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# SITUATIONAL AWARENESS: A FEASIBILITY INVESTIGATION OF NEAR-THRESHOLD SKILLS DEVELOPMENT

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A decisive capability possessed by superior fighter-attack pilots is keen situational awareness. In this report, we examine the trainability of near-threshold information acquisition and processing skills that appear to be vital to heightened situational awareness. The investigation served two purposes: (a) determine the effects or near-threshold training on target detection, recognition, and identification performance; and (b) assess the general transfer of this training to velocity discrimination and peripheral vision two-flash threshold performance. Ten flight-qualified AFROTC cadets served as trainees. Each trainee received 5,040 near-threshold training trials over five consecutive days. The findings indicate that near-threshold skills are trainable. Group and individual learning curves reflected consistent improvement in target detection, recognition, and identification accuracy at target durations down to 33 ms. Statistically significant differences were found between group baseline and post-training performance. The general transfer of training data showed enhanced peripheral vision two-flash threshold performance, but very little change in velocity discrimination performance.

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## FOREWORD

The feasibility investigation described herein was conducted during the Fall of 1987. The present technical report is a complete documentation of that research and supersedes an earlier preliminary reported dated March 1988. The results of the feasibility investigation led to a Small Business Innovation Research (SBIR) Program Phase II effort which produced a prototype situational awareness training system, delivered to the Armstrong Laboratory in 1991.

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The participation of ten cadet trainees from AFROTC Detachment 840A, University of Texas San Antonio, was crucial to the success of this project. We want to express our appreciation for their diligence and hard work. Finally, we wish to acknowledge and thank Narcie Secrist for outstanding secretarial and administrative support. We appreciate her efforts in support of this research.

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# INTRODUCTION

## Tactical Aircrew Performance

The history of aerial combat demonstrates that tactical mission effectiveness hinges on the extraordinary performance of a few superior fighter-attack pilots (e.g., deLeon, 1977; Franks, 1986; Secrist, 1986; Shores, 1983; Youngling, Levine, Mocharnuk, & Weston, 1977). Relevant research suggests that superior fighter-attack pilots have identifiable characteristics that distinguish them from their less successful contemporaries (e.g., deLeon, 1977; Hartman & Secrist, 1991); Kelly, Wooldridge, Hennessy, Vreuls, Barneby, Cotton, & Reed, 1979; Secrist, 1986; Torrance, Rush, Kohn, & Doughty, 1957; Yeager & Janos, 1985; Youngling et al., 1977). These differentiating characteristics appear to include highly developed perceptual and cognitive capabilities as well as personal attributes such as aggressiveness, independence, competitiveness, and the ability to tolerate and manage stress. One of the most pervasive characteristics of superior fighter-attack pilots is extraordinary situational awareness.

## Situational Awareness

A prominent distinguishing feature of superior situational awareness is the capacity to function in an anticipatory rather than reactive mode, an asset that is decisive in the complex and highly fluid air combat environment. The essence of this anticipatory dimension of situational awareness has been captured by Forrester (1978).

> There is some sixth sense that a man acquires when he has peered often enough out of a perspex capsule into a hostile sky -- hunches that come to him, sudden and compelling, enabling him to read signs that others don't even see. Such a man can extract more from a faint tangle of condensation trails, or a distant flitting dot, than he has any reason or right to do (Forrester, 1978, p. 229).

We believe that aircrew situational awareness is comprised of four essential components which serve to define the concept.

1. Exceptional sensitivity to performance-critical cues in the flight environment.

2. Heightened awareness of aircraft status and operational conditions.

3. Remarkable cognizance of the total combat situation and related priorities.

4. An uncanny ability to <u>anticipate</u> changes in aircraft system states, operational conditions, and the dynamic air combat situation.

In our view, situational awareness is crucial to aerial combat performance in two respects.

1. Heightened situational awareness provides the information required for unerring, real-time situation assessment and decision-making under great time urgency and stress.

2. Keen situational awareness produces lead-time by providing access to performance-critical information not yet available to an adversary. This lead-time, in turn, is vital to achieving surprise and seizing the initiative.

<u>Theoretical Framework</u>

The theoretical and methodological basis for our conceptualization of human performance can be found in several recent publications (Hartman & Secrist, 1991; Secrist & Hartman, 1993a, 1993c; Secrist, Hartman, Gallaway, & Smith, 1991). These publications provide a new conceptualization of human performance that incorporates situational awareness, identifies relevant skills, specifies training methods, and documents efforts to develop a situational awareness training system. The present investigation focuses on the skill structure that has emerged from our theoretical-conceptual work.

Certain primary skills appear to be crucial to performance in high-demand tasks such as those performed by fighter-attack pilots during combat. We have classified these skills as Human Performance I, or HP I skills (Secrist & Hartman, 1993a; Secrist et al., 1991). The HP I skills have been categorized into three domains: situational awareness, decision, and response domains as shown in Table 1.

The awareness skills listed in Table 1 accentuate the importance of: (a) acquiring performance-critical cues in a near-threshold state, (b) rapidly integrating those cues into an accurate situation assessment, (c) direct apprehension of situation dynamics, and (d) anticipatory rather than reactive judgment in response to changing events. These skills operate to provide accurate and timely information as a basis for decision-making and action. HP I task environments are extremely dynamic and decision time is severely compressed. Thus, the information needed for valid decisions must be acquired very early.

The requirement for early information acquisition is addressed by the first three skills in the awareness domain (see Table 1). These skills have been designated near-

TABLE 1

HP I Skill Domains and Primary Skills

| Situational Awareness Domain |
|---|
| 1. Heightened sensitivity to extremely short-duration, low intensity cues in the external stimulus field. |
| 2. Early acquisition of critical cues and patterns. |
| 3. High-speed integration of cues and patterns to determine significance. |
| 4. Instantaneous situation assessment from minimal input information. |
| 5. Direct apprehension of situation dynamics and trends. |
| **Decision Domain** |
| 6. Sound anticipatory judgment regarding decision options and related consequences. |
| 7. Valid intuitive decisions under conditions of time urgency and stress. |
| **Response Domain** |
| 8. Refined automaticity in mapping cue patterns to optimum response programs. |
| 9. Extraordinary precision in response execution. |

threshold skills. The term "near-threshold" refers to acquiring and processing sensory stimuli near, at, or below the level of conscious awareness. The word "subthreshold", as used in this report, concerns stimuli in a region above neurophysiological awareness, but below conscious awareness.

Two advantages are anticipated from the development of near-threshold skills: critical information is acquired sooner, and a wider range of information is accessible. A likely consequence of these advantages is that the information needed for valid decisions is available earlier, resulting in enhanced decision speed and accuracy.

An important question is whether the near-threshold skills can be developed and refined through special training. We postulate that: (a) training in near-threshold information acquisition and processing will increase sensitivity to low-intensity, short-duration cues in the stimulus environment; (b) the acquisition and integration of performance-critical cues in their near-threshold state will heighten situational awareness; and (c) the early availability of important task-relevant information will enhance decision speed and accuracy.

## Empirical Foundation

Research relevant to the near-threshold skills provides rather substantial evidence that very low intensity or extremely brief, fleeting sensory cues can affect various kinds of performance. These performance effects include semantic orientation of verbal behavior, linguistic analysis, visual and auditory judgments, lexical decisions, problem solving, and decision speed and accuracy (e.g., Balota, 1983; Dixon, 1971, 1981; Erdelyi, 1974; Fowler, Wolford, Slade, & Tassinary, 1981; Holender, 1986; Klatzky, 1984; Lyon, 1987; Marcel, 1983; Secrist, 1986; Secrist & Hartman, 1993c; Wolford, Marchak, & Hughes, 1988).

The concepts of automated processing and response automaticity also appear to be closely related to the near-threshold skills as well as high-demand performance (HP I). These concepts and associated empirical research emanate from the two-process model of information acquisition and processing (e.g., Fisk & Lloyd, 1988; Fisk, Oransky, & Skedsvold, 1988; Logan, 1988; Schneider, 1985; Schneider & Detweiler, 1988; Schneider, Dumais, & Shiffrin, 1984; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). The two-process model distinguishes between two qualitatively different modes of information acquisition and processing: one mode that is primarily automatic and performed with minimal conscious attention; and another mode that is controlled, contemplative, and acutely conscious.

Extensive response automaticity characterizes most highly skilled performance behaviors (Fitts & Posner, 1967).

Superior fighter-attack pilots, for example, appear to automate all routine activities, smoothly accomplishing even complex tasks with little or no conscious attention. These automatic processes are the result of long, intensive training and practice involving consistent mapping between task-related stimulus patterns and various response repertoires. It is likely that the automated behaviors that characterize highly skilled performance are triggered by subtle, near-threshold cues and patterns.

## RESEARCH OBJECTIVES

The purpose of this research was to investigate the trainability of a principal component of superior situational awareness: near-threshold information acquisition and processing. Trainability was determined by assessing performance on three tasks essential to tactical aircrew effectiveness: target detection, target recognition, and target identification.

A secondary purpose of the research was to ascertain whether enhanced near-threshold skills, as demonstrated on the three training tasks, would translate to other tasks dependent on the resolution of near-threshold stimuli. Two tasks were selected to test this general transfer of training hypothesis: velocity discrimination and peripheral vision two-flash threshold.

## METHODOLOGY

### Training Paradigm

The experimental design included specific and general transfer of training models (Figure 1). The specific transfer model incorporated three data acquisition segments: pre-training or baseline, training, and post-training segments. The general transfer model employed only baseline and post-training assessments.

Two types of training effectiveness measures were employed: (a) direct transfer of training to assess near-threshold training effects on target detection, recognition, and identification performance; and (b) general transfer of training to assess the extent near-threshold training generalized to two other exacting tasks, velocity discrimination and peripheral vision two-flash threshold. The baseline and post-training segments were identical for each of the three direct transfer of training protocols (target detection, recognition, and identification) as well as for the two general transfer of training protocols (velocity

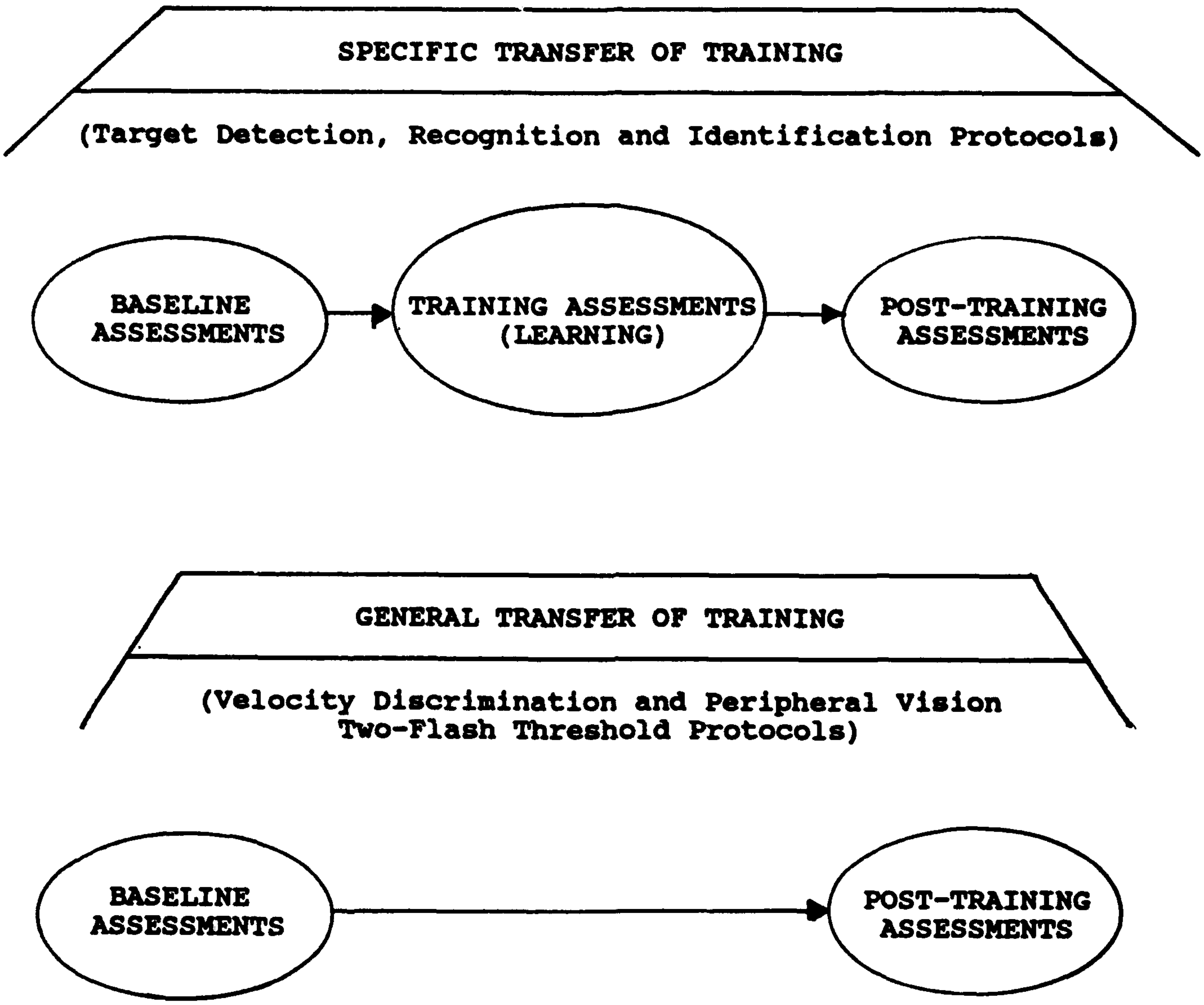



Figure 1. Experimental design for training and general transfer of training.

discrimination and peripheral vision two-flash threshold). However, for the direct transfer protocols, an intense training segment was interposed between the baseline and post-training assessments. This training segment was not, of course, interposed between the baseline and post-training assessments of the two general transfer protocols.

## Apparatus and Equipment

Appropriate experimental apparatus and training equipment were assembled in a separate laboratory devoted exclusively to the conduct of the feasibility investigation. The laboratory space consisted of a single room approximately 200 $ft^2$ in size. Solid doors, carpeted floors, and wood-paneled walls provided a comfortable, quiet enclosure for the training. Two training stations and one control station were assembled in the laboratory space (see Figure 2). The training stations are designated TS 1 and TS 2.

### Training Station 1 (TS 1)

TS 1 was used to administer the target identification, recognition, and identification protocols as well as the velocity discrimination protocol. TS 2 was used to administer the peripheral vision two-flash threshold protocol. The investigator's control station was used to initiate and regulate the training process as well as to accomplish data management and analysis.

TS 1 consisted of a medium resolution (640-pixel x 240-line) 13-in. Magnavox RGB Monitor 80 (Model CM 8562 color video monitor), a hood with a view-port, a chinrest stand, and two response controls (Radio Shack joysticks, Model 270-1701). The video monitor rested on a 10.5-in. platform positioned on a table that was 31 in. high. Viewing distance was controlled at 28 in. by means of a hood and Tectronix binocular view-port attached to the video monitor. The interior of the hood was painted flat black to eliminate reflection and glare.

An adjustable stand with a chinrest controlled head movement and provided a comfortable interface with the hood view-port. Right and left hand joysticks were ergonomically located on the table top. The joystick position could be varied to accommodate trainee body size and to furnish a firm, comfortable base for control movement. A padded stool could be adjusted to vary seat height in relation to the chinrest and hood view-port.

### Training Station 2 (TS 2)

TS 2 consisted of a peripheral light display mounted on a display platform with adjustable legs and a padded headrest. TS 2 also included a chinrest stand, and one Radio Shack joystick (Model 270-1701) that was used to input trainee

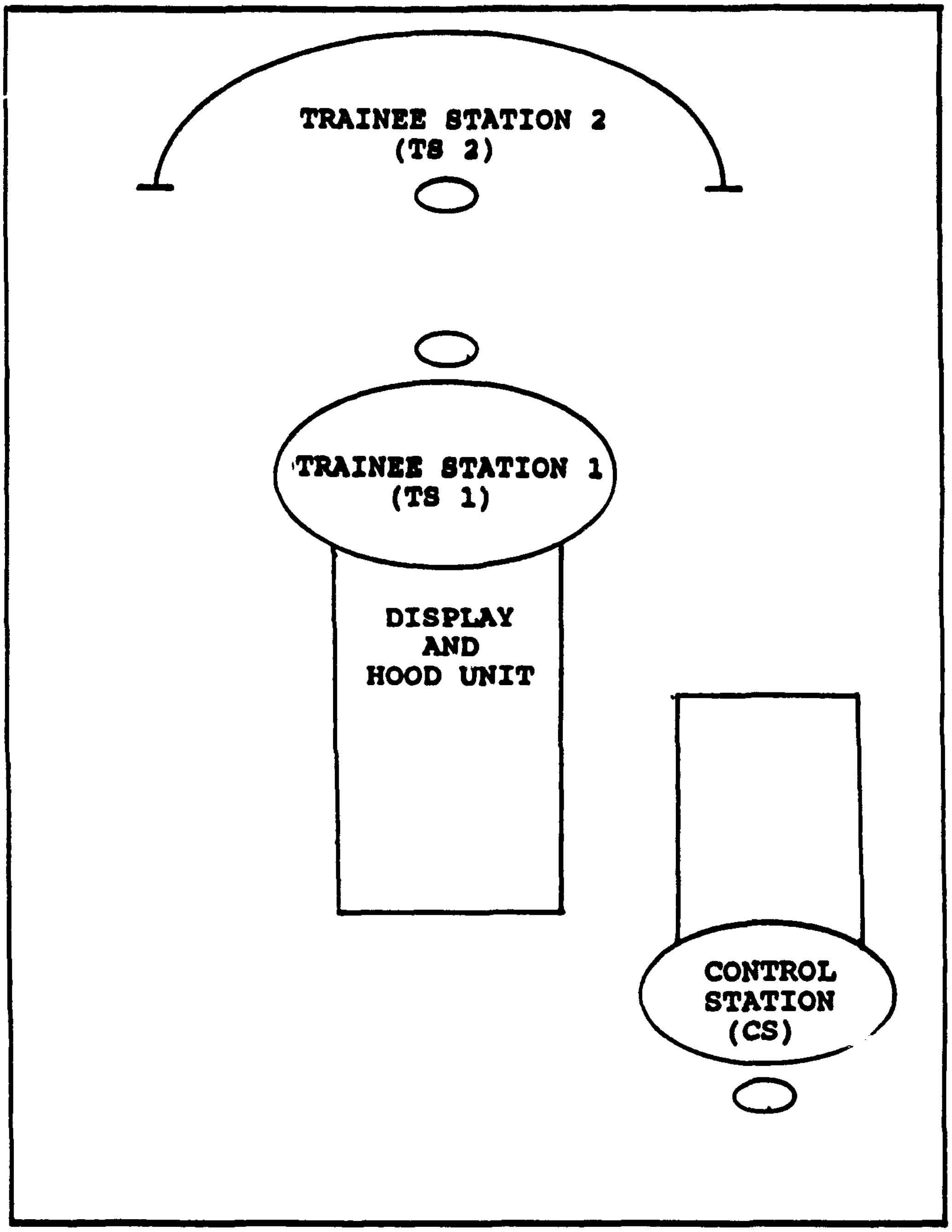



**Figure 2. Laboratory layout for near-threshold training investigation.**

responses. The peripheral light display contained an array of 13 red light emitting diodes (LEDs) aligned at 15-degree intervals along the horizontal meridian. The LEDs were mounted in a curved panel 4 in. high and constructed in a 180 degree semicircle. The curved LED display panel was attached to the top of the peripheral display platform.

The peripheral display platform was constructed of half-inch plywood. The platform was supported by adjustable legs that could be used to vary the height of the display. The platform legs rested on a 31-in. high table. Except for the red LEDs, the entire surface of the peripheral display was painted flat black.

An adjustable stand with a chinrest was positioned on the table to stabilize the head as it rested against the padded headrest of the peripheral display platform. The platform's padded head groove served two purposes: (a) to minimize head movement, and (b) to fix the viewing distance at 22.5 in. from the LEDs to the eye reference point.

A single joystick for the right hand was located on the table; its position could be varied to provide a stable, comfortable foundation for control movement. The same padded, adjustable stool used in TS 1 was moved to TS 2 for the peripheral vision protocol. The adjustable stool made it easy to vary seat height in relation to the chinrest and peripheral light display platform.

Control Station (CS)

The investigator control station (CS) consisted of a computer, keyboard, displays, printer, and software programs for training protocol administration and data acquisition. In addition to controlling the administration of the training protocols, data collection, storage, formatting, and analyses were also accomplished at the control station. The location of the control station in relation to TS 1 and TS 2 precluded visual access by the trainee.

An IBM-compatible XT computer (CompuAdd Standard Brand Model), augmented with additional memory boards, provided the computational power. This system, as modified, comprised a total of 20 megabytes of memory storage and nearly 2 megabytes of operating memory (RAM). The principal control station display was a 12-in. monochrome (amber phosphor) Samsung video monitor (Model MD-1254G). An additional 13-in. monochrome (green phosphor) Amdek video monitor (Model 300) was used to administer the velocity discrimination protocol.

The computer programs developed to implement and control the training protocols were formulated especially for the near-threshold training research. Data were formatted using the Lotus 1-2-3 spreadsheet program; it was analyzed according

to a data analysis model discussed later. An Epson LX-800 printer provided data printouts and program documentation.

## Training Protocols

Separate experimental protocols were prepared on each of five experimental tasks. The protocols specified the content and sequence of events for the three direct and the two general transfer of training protocols. Major training variables were categorized as dependent, independent, and control as depicted in Table 2. Computer programs and related software were developed to implement and regulate protocol content and timing functions.

The fundamental element of each protocol was an individual training trial consisting of a precisely defined event/time profile. The event/time profiles for the target detection, recognition, and identification protocols were identical except for the stimuli presented during the target visual access time and the number of possible response options (see Figure 3). Each training trial was initiated by the appearance of a fixation cross in the center of the video monitor for 1 sec, immediately followed by one of the stimulus alternatives used in the detection, recognition, or identification protocols (target, nontarget, or vertical light bar). A binocular pattern mask that consisted of a solid face form replaced the stimulus at the specified time to precisely control visual access time. The pattern mask remained on the video monitor for 500 ms. The trainee responded by activating a joystick control during the 1.5-sec response window which followed the pattern mask.

A variable intertrial interval was programmed into the trial timeline to complete the trial in exactly four seconds. The length of this interval was determined by the particular visual access time utilized in the trial. Upon completion of the 4-sec trial, the fixation cross reappeared to start the next trial.

Each of the three near-threshold direct transfer protocols represented a different level of complexity: target detection was the easiest; target recognition was of intermediate complexity; and target identification was the most difficult. The complexity of these protocols was a function of: (a) visual discrimination difficulty (e.g., number of possible targets/nontargets as well as their shape and relative similarity), (b) target/nontarget visual access time, and (c) number of possible response options.

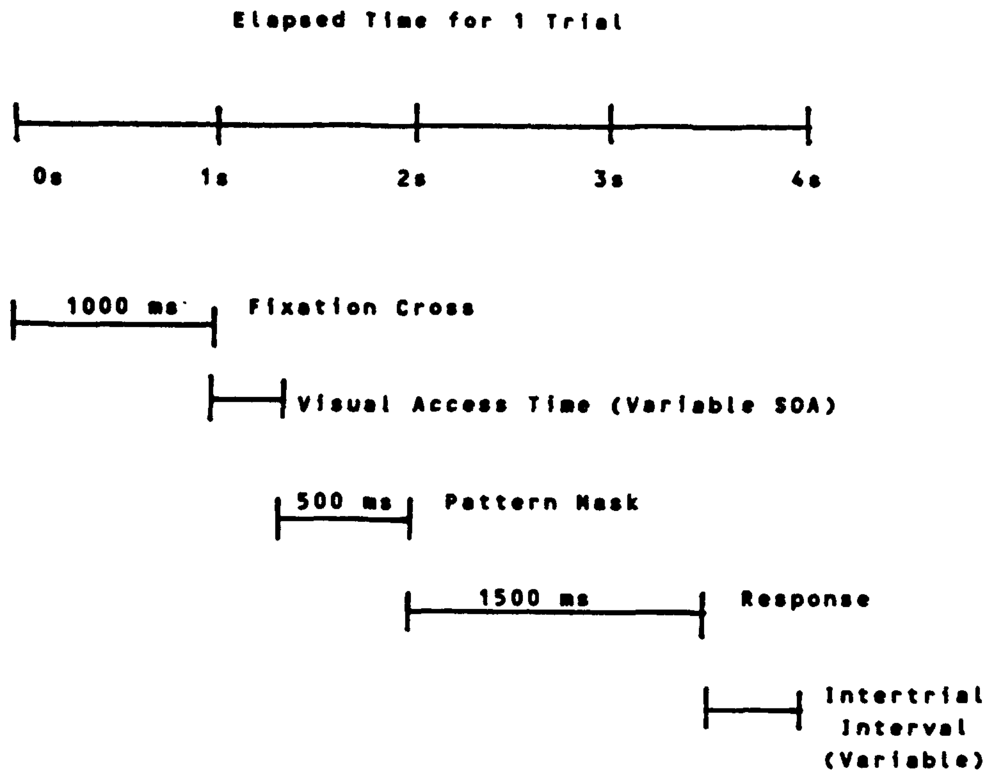
The targets/nontargets and associated response options utilized in the detection, recognition, and identification protocols are depicted in Table 3. A variety of solid, visual-spatial forms of different shape and relative similarity are represented. The target stimuli depicted in

TABLE 2

Major Training Variables

| Performance or Dependent Variables |
|---|
| **Performance Variables (Specific Transfer of Training)**<br>• Target Detection Accuracy<br>• Target Recognition Accuracy<br>• Target Identification Accuracy |
| **Performance Variables (General Transfer of Training)**<br>• Velocity Discrimination<br>• Two-Flash Threshold |
| **Independent Variables** |
| **Independent Variables (Specific Transfer of Training)**<br>• Visual access time as measured by stimulus onset asynchrony (SOA). SOA is the time lapse between a stimulus and pattern mask.[a]<br>• Training intensity as measured by number of training trials.<br>• Protocol difficulty: Three levels represented from least to most difficult as: Target Detection, Target Recognition, and Target Identification. |
| **Independent Variables (General Transfer of Training)**<br>• Circle Expansion Velocity of Standard Stimulus<br>• Circle Expansion Velocity of Test Stimulus<br>• Two-Flash Inter-stimulus Interval<br>• Two-Flash Stimulus Eccentricity<br>• Single Flash Foil |
| **Control Variables** |
| • Stimulus Shape<br>• Stimulus Size<br>• Stimulus Intensity<br>• Stimulus Contrast<br>• Stimulus Color<br>• Illumination Ratio (Stimulus to Background)<br>• Background Color<br>• Lighting Specifications<br>• Viewing Distance |

[a]As used in this report, the following terms are synonymous: visual access time, stimulus onset asynchrony (SOA), stimulus duration, target duration, and temporal duration.




| Protocol | Stimulus Options | Response Options |
|---|---|---|
| Target Detection | 5 | 2 |
| Target Recognition | 10 | 2 |
| Target Identification | 10 | 5 |

Figure 3. Step-wise plot of major segments of the trial event and time profile for target detection, recognition, and identification protocols. Stimulus and response options for each training protocol are also shown. Note that stimulus visual access time (SOA) is too brief to be accurately plotted against the time scale.

Table 3 actually appeared as solid silver-gray forms centered on the medium blue background of a color video monitor, not as black forms on a white background as illustrated in Table 3.

Target Detection

The objective of target detection training was to sharpen detection sensitivity with respect to fleeting, extremely brief duration (millisecond) targets presented in the foveal visual field. Four targets (heart, diamond, spade, club) were randomly mixed with a vertical light bar (nontarget) so that the target and nontarget conditions were each presented about 50 percent of the time. Each target detection trial consisted of a 4-sec timeframe (Figure 3).

The trainee task was to detect the presence of any of the four targets (see Table 3). Two response options were possible. If the trainee detected one of the targets, the proper response was to push the right-hand joystick forward. If the trainee concluded that no target was present during the presentation interval, the correct response was to press the red thumb button on top of the right-hand joystick.

Target Recognition

The goal of target recognition training was to improve the categorization of fleeting, short-duration targets. In this training, the trainee task was to discriminate solid visual-spatial target symbols (heart, diamond, spade, club) from other variable-shaped, nontarget forms (see Table 3). Four target symbols, five nontarget symbols, and a blank (no stimulus symbol) were randomly presented in the target window for the specified visual access time period. The event/time profile for the target recognition training was identical to that used for target detection training except for the number of stimulus alternatives presented in the stimulus window (see Figure 3).

The response options for the target recognition training were the same as for target detection training. Although detection training involved five discrimination alternatives in contrast to ten discrimination alternatives for recognition training, both types of training required two response options. In the case of target detection training, the trainee was required to detect the presence of the target and indicate whether or not a target was present. For target recognition training, the trainee was asked to recognize and classify the stimuli into two categories: target or nontarget. The right-hand joystick was pushed forward when a target symbol was recognized; the red thumb button on top of the right-hand joystick was used when a nontarget symbol was recognized.

TABLE 3

Stimulus Characteristics and Response Options: Specific Transfer Protocols

---

Target Detection Protocol

---

Stimulus Options[a]

- Targets ♠ ♣ ♦ ♥
- Nontargets I

Pattern Mask ☻

Response Options

- Right-hand joystick forward for target
- Right-hand joystick thumb-button for nontarget

---

Target Recognition and Identification Protocols

---

Stimulus Options[a]

- Targets ♠ ♣ ♦ ♥
- Nontargets ▮ ✲ ▬ ▼ ▲

Pattern Mask ☻

Response Options for Target Recognition Protocol

- Right-hand joystick forward for target
- Right-hand joystick thumb-button for nontarget

Response Options for Target Identification Protocol

- Right-hand joystick forward for heart symbol, back for diamond symbol.
- Left-hand joystick forward for spade symbol, back for club symbol.
- Right-hand joystick thumb-button for nontarget.

---

[a]An empty display (blank screen) or nonstimulus option was included with the target and nontarget options that were randomly selected for display.

## Target Identification

Target identification training was designed to improve near-threshold processing to the point that specific targets could be accurately identified from fleeting, short-duration cues. The stimuli consisted of the same four randomly generated visual-spatial target symbols, five nontarget symbols, and a blank (no stimulus symbol) that were utilized for target recognition training (see Table 3). However, for target identification training, the trainees were required to specifically identify each target. The event/time profile for the target identification training was identical to that used for detection and recognition training (See Figure 3).

Additional control options were required for target identification training because a different response was appropriate for each of the four targets, and a fifth response was needed to respond to the nontargets. Accordingly, both left-hand and right-hand joysticks were employed. The right-hand joystick was used to identify the heart and diamond target symbols; the joystick was pushed forward to indicate that a heart had been identified and pulled back to indicate that a diamond had been identified. The left-hand control stick was used to identify spade and club target symbols; the joystick was pushed forward when the spade was identified and pulled back when the club was identified. If one of the five nontargets appeared, the trainee was required to push the red thumb button on the right-hand joystick.

## General Transfer Protocols

The stimuli and response options for the general transfer of training protocols are summarized in Table 4. The general transfer protocols were designed to assess general training effects; therefore, no training was accomplished between the baseline and post-training assessments. Accordingly, the protocols were administered only twice, once as a baseline assessment and once after the direct training in target detection, recognition, and identification was completed.

## Velocity Discrimination

This protocol was formulated to measure the extent to which near-threshold training generalized to velocity discrimination performance. The velocity discrimination measure was based on the expanding flow pattern approach developed by Regan and his colleagues (Kruk & Regan, 1983; Kruk, Regan, Beverley, & Longridge, 1983; Regan, 1983, 1984; Regan, Beverley, & Cynader, 1979). The expanding flow pattern was created by the outward flow or motion of ten silver-gray concentric circles on the blue background of a color video monitor.

**TABLE 4**

**Stimulus Characteristics and Response Options: General Transfer Protocols**

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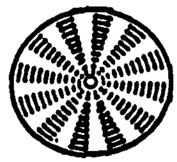
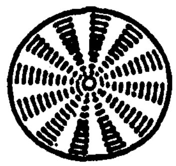
**Velocity Discrimination Protocol**

---

**Stimuli**

- **Standard stimulus** 

- **Test stimulus** 

**Response**

- **Right-hand joystick forward if test stimulus expansion rate is faster than standard.**

- **Right-hand joystick back if test stimulus expansion rate is slower than standard.**

---

**Two-Flash Threshold Protocol**

---

**Stimulus**

- **Red LEDs at three locations ($0^\circ$, $45^\circ$L, $45^\circ$R): Two-flashes at variable Interflash Interval (IFI).**

- **Red LEDs at three locations ($0^\circ$, $45^\circ$L, $45^\circ$R): Single flash.**

**Response**

- **Right-hand joystick forward if two flashes are perceived.**

- **Right-hand joystick back if one flash is perceived.**

---

The velocity discrimination protocol required trainees to discern very small differences in the relative expansion velocity of concentric rings of standard and comparative test circles. On each trial, trainees compared the expansion rates of the two circles with a 3-sec delay interposed between the standard and test circles. The standard circle had an expansion velocity of 1.4 degrees/sec. The test circle was presented at one of four randomly generated test velocities: two faster than the standard (0.05 and 0.1 degrees/sec faster) and two slower than the standard (0.05 and 0.1 degrees/sec slower). After presentation of both the standard velocity and one of the randomly generated test velocities, the trainee used a joystick control to indicate whether the comparative velocity of the test circle was faster or slower than the velocity of the standard circle.

Figure 4 portrays the event/time profile of the velocity discrimination protocol. As indicated, a trial began when the fixation cross appeared in the center of the video monitor. After 1 sec, the fixation cross was replaced by the standard velocity pattern, which remained on the video for 2 sec. A delay interval of 3 sec followed, then one of the four randomly generated test velocity patterns was presented. The test velocity pattern, like the standard velocity pattern, remained on the video for 2 sec, followed by a 2-sec window during which the trainee indicated his response using the joystick.

Two response options were possible. The right-hand joystick was pushed forward if the velocity of the second (test) circle was faster than that of the first (standard) circle, and pulled back if the velocity of the second circle was slower than that of the first circle. A single velocity discrimination trial involved a lapse time of 10 sec. After completion of each trial, the fixation cross reappeared to signify the start of another trial.

### Peripheral Vision Two-Flash Threshold

The objective of the peripheral vision two-flash threshold protocol was to assess the extent to which fovea-oriented, near-threshold training enhanced peripheral vision resolving power. The two-flash threshold measure was used to index visual resolving power.

A peripheral light display provided the primary stimulus inputs. The display consisted of 13 dimly lit red light emitting diodes (LEDs) aligned at 15-degree intervals along the horizontal meridian. As explained earlier, the LED display was formed in a 180-degree semicircle that extended to 90 degrees in both the left and right visual periphery.

Two different types of peripheral processing protocols were developed. The intent of the first protocol was to

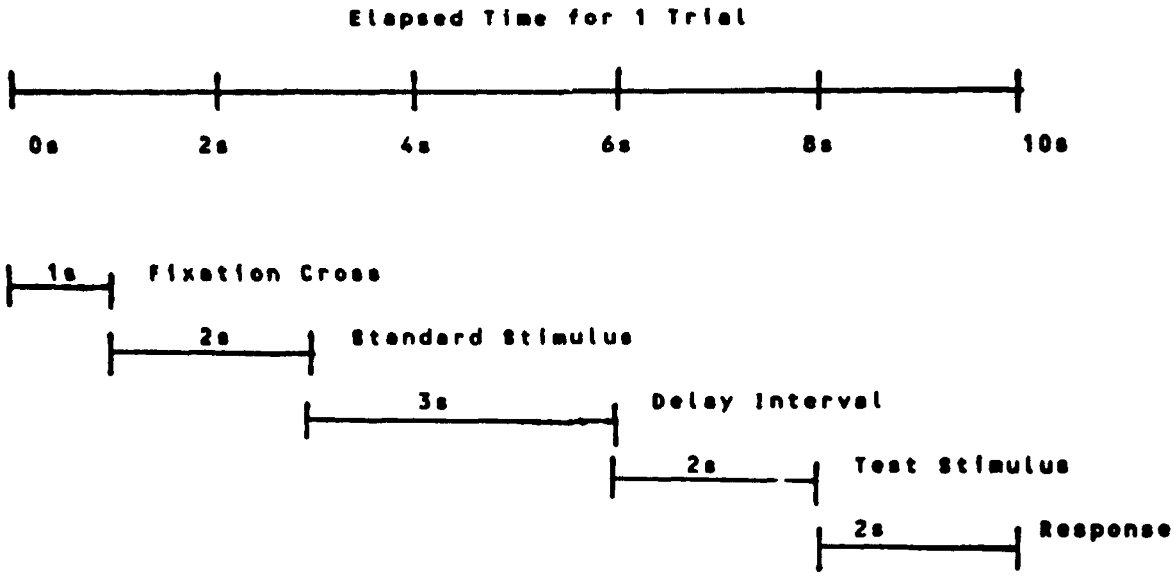



Figure 4. Step-wise plot of major segments of the trial event and time profile for the velocity discrimination protocol.

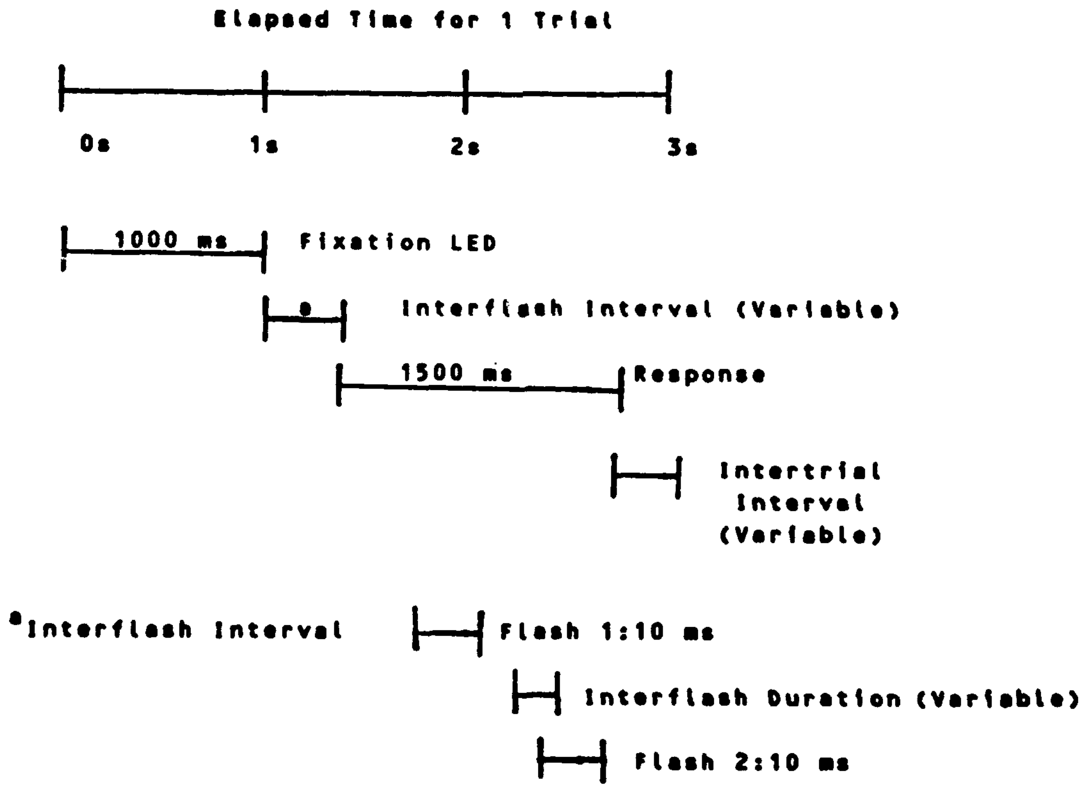



Figure 5. Step-wise plot of major segments of the trial event and time profile for the peripheral vision two-flash threshold protocol. Note that the interflash interval is too brief to be accurately plotted against the time scale.

establish a rough estimate of each trainee's two-flash threshold. Each individual's two-flash threshold was then used to establish a personalized standard for the baseline and post-training assessments.

A separate two-flash threshold was established on each trainee for three light positions: central reference position (0 degrees), 45 degrees left of the central reference position, and 45 degrees right of the central reference position. A light in one of these three positions flashed twice; interflash intervals (IFI) were variable. The trainees were required to indicate whether they perceived one or two flashes.

For threshold determination, the IFI began at 120 ms and decreased in 10-ms intervals until an error was made. When an error was made on a two-flash discrimination trial, the IFI was adjusted according to a specified decision rule until performance diminished to a rough approximation of chance. The decision rule specified that the IFI be increased or decreased in 5-ms increments of five trials each until performance stabilized at about the chance level.

The subsequent peripheral two-flash baseline and post-training assessments were geared to each trainee's personal threshold. Eleven two-flash IFIs were randomly generated at each of the three light positions. Randomly generated two-flash IFIs were selected from a pool that ranged from 20 ms below to 20 ms above (in 4-ms intervals) each individual's baseline threshold. Three single-flash foils were also randomly presented at each of the three light positions. The single-flash foils were generated at three durations: (a) shortest IFI plus 20 ms, (b) longest IFI plus 20 ms, and (c) equidistant between the shortest and longest IFI.

Figure 5 (page 18) depicts the trial event/time profile for the peripheral vision two-flash baseline and post-training assessments. Trainees focused on the central LED for 1 sec to begin each trial. Next, a randomly selected two-flash IFI or single-flash foil was administered. If a two-flash stimulus was generated, the first flash appeared for 10 ms, followed by the specified IFI, then the second flash for 10 ms. If a single flash was generated, it remained on for 10 ms, with no subsequent second flash. A variable intertrial interval (dependent on the IFI and the one versus two flash alternative) permitted the total lapse time for each trial to be standardized at 3 sec.

To begin the peripheral processing task, the trainees were seated in front of the semi-circular light display in a darkened room. Trainees were dark-adapted and instructed to fixate on the center LED. Their task was to detect when a particular light flashed (increased in intensity) and to determine whether it flashed once or twice. A 1.5-sec period

was provided for response selection following administration of the flash stimuli. All peripheral processing trials required only a single decision on the part of the trainee: to determine whether one or two flashes had occurred. A right-hand joystick was pushed forward if two flashes were detected and pulled back if a single flash was detected.

Procedures

Control of Visual Access Time

Pattern masking was used to precisely regulate the duration of access to visual information. The pattern masking procedure involved the application of a pattern mask at some temporal duration (in milliseconds) following stimulus onset in order to terminate the orderly acquisition and processing of the stimulus information. The pattern or contour information contained in the masking stimulus degrades the quality of the original stimulus. The time interval between onset of the stimulus and the onset of the pattern mask is known as stimulus onset asynchrony (SOA).

Pattern masking was initially used to demonstrate that complex visual stimuli could be acquired, processed, and stored even when they were presented for extremely short durations (Averbach & Coriell, 1961; Sperling, 1963; 1967). More recently, pattern masking techniques have been utilized to study the acquisition and processing of extremely brief, low-intensity information at or near the threshold of conscious awareness, including stimulus intensities and durations in the region between neurophysiological awareness and conscious awareness (Dixon, 1981; Klatzky, 1984; Marcel, 1983; Wolford et al., 1988).

Pattern masking techniques can yield valuable insight about the time course and nature of the perceptual-cognitive processes. By varying the time of mask onset (SOA) in relation to a particular stimulus or stimulus array, the influence of the masking stimulus on information acquisition and processing can be examined along a millisecond time base. Even extremely brief SOAs permit the acquisition and processing of semantic content and certain physical characteristics. This situation holds even when the brevity of the SOA time interval is reduced to the point that conscious awareness is precluded (e.g., see Dixon, 1981; Marcel, 1983).

The SOAs or visual access windows for the three near-threshold direct transfer of training protocols ranged from 250 ms down to 17 ms as shown in Table 5. SOA durations for the target detection baseline and post-training assessments were: 17, 33, 50, 67, 83, and 100 ms. Baseline and post-training assessments for target recognition and identification were nearly identical to target detection, except that one

longer SOA (150 ms) was added for target recognition; and two longer SOAs (150 and 250 ms) were added for target identification to permit longer visual access early in the training for more complex protocols.

All of the target detection, recognition, and identification training trials (in contrast to baseline and post-training trials) were concentrated at two SOAs: 33 and 67 ms. It was hypothesized that intensive training at these levels would transfer to performance at other SOAs as well as to performance on the two general transfer tasks.

A final word about the use of SOA in this research report. We have used a number of terms as synonymous with SOA and employed these terms as conceptually and operationally interchangeable with SOA: visual access time, stimulus duration, target duration, and temporal duration.

### Control of Experimental Variables

Certain stimulus characteristics were fixed to minimize confounding influences, control unwanted variation, and permit the isolation of training effects. The control variables and their fixed values for both training and general transfer protocols can be found in Tables 6 and 7, respectively.

Before the start of the investigation, appropriate experimental apparatus and training equipment were calibrated to the desired specifications. The dimensions of the various display symbols were measured and viewing distance calculated to attain the desired visual angles. Illumination ratios between the various target and nontarget symbols and the video background were measured using a spot light meter.

All training and assessments were conducted with the laboratory lights turned off to preclude light leakage into the view-port and hood. The peripheral vision two-flash threshold protocol was conducted with dimly lit red LEDs in an otherwise darkened room. A 10-min dark adaptation period always preceded data acquisition on this protocol.

Precise timing of the training sequence, experimental functions, and display update (60 Hz) was accomplished by a 1.14 MHz computer clock. This clock was used to satisfy the timing requirements of the training regimes, including visual access, stimulus initiation, stimulus cessation, and pattern mask operation. The 1-min rest periods between training blocks were also controlled by the computer clock. Timing of the longer interprotocol rest periods was accomplished using a standard commercial stopwatch.

Table 5

Stimulus Temporal Durations: Specific Transfer Protocols

| Session | Target Detection | | | Target Recognition | | | Target Identification | | |
|---|---|---|---|---|---|---|---|---|---|
| | B[a] | T[b] | SOA[c] (ms) | B[a] | T[b] | SOA[c] (ms) | B[a] | T[b] | SOA[c] (ms) |
| Day One: | | | | | | | | | |
| Baseline | 1 | 20 | 100 | 1 | 20 | 150 | 1 | 20 | 250 |
| | 1 | 20 | 83 | 1 | 20 | 100 | 1 | 20 | 150 |
| | 1 | 20 | 67 | 1 | 20 | 83 | 1 | 20 | 100 |
| | 1 | 20 | 50 | 1 | 20 | 67 | 1 | 20 | 83 |
| | 1 | 20 | 33 | 1 | 20 | 50 | 1 | 20 | 67 |
| | 1 | 20 | 17 | 1 | 20 | 33 | 1 | 20 | 50 |
| | | | | 1 | 20 | 17 | 1 | 20 | 33 |
| | | | | | | | 1 | 20 | 17 |
| Day Two: | | | | | | | | | |
| Training | 10 | 200 | 67 | 10 | 200 | 67 | 10 | 200 | 67 |
| | 10 | 200 | 33 | 10 | 200 | 33 | 10 | 200 | 33 |
| Day Three: | | | | | | | | | |
| Training | 10 | 200 | 67 | 10 | 200 | 67 | 10 | 200 | 67 |
| | 10 | 200 | 33 | 10 | 200 | 33 | 10 | 200 | 33 |
| Day Four: | | | | | | | | | |
| Training | 10 | 200 | 67 | 10 | 200 | 67 | 10 | 200 | 67 |
| | 10 | 200 | 33 | 10 | 200 | 33 | 10 | 200 | 33 |
| Day Five: | | | | | | | | | |
| Training | 5 | 100 | 67 | 5 | 100 | 67 | 5 | 100 | 67 |
| | 5 | 100 | 33 | 5 | 100 | 33 | 5 | 100 | 33 |
| Day Five: | | | | | | | | | |
| Post-training | 1 | 20 | 100 | 1 | 20 | 150 | 1 | 20 | 250 |
| | 1 | 20 | 83 | 1 | 20 | 100 | 1 | 20 | 150 |
| | 1 | 20 | 67 | 1 | 20 | 83 | 1 | 20 | 100 |
| | 1 | 20 | 50 | 1 | 20 | 67 | 1 | 20 | 83 |
| | 1 | 20 | 33 | 1 | 20 | 50 | 1 | 20 | 67 |
| | 1 | 20 | 17 | 1 | 20 | 33 | 1 | 20 | 50 |
| | | | | 1 | 20 | 17 | 1 | 20 | 33 |
| | | | | | | | 1 | 20 | 17 |
| Totals | 82 | 1640 | NA | 84 | 1680 | NA | 86 | 1720 | NA |

[a]Training Blocks
[b]Training Trials
[c]Stimulus Onset Asynchrony (SOA) in milliseconds (ms)

TABLE 6

Control Variables: Measured Values for Target Detection, Recognition, and Identification Protocols

| Stimuli | Length | | Width | |
|---|---|---|---|---|
| | mm | Visual Angle (Degrees) | mm | Visual Angle (Degrees) |
| Target Symbols | | | | |
| ● Heart | 8 | .64 | 6 | .48 |
| ● Diamond | 8 | .64 | 6 | .48 |
| ● Spade | 8 | .64 | 6 | .48 |
| ● Club | 8 | .64 | 6 | .48 |
| Nontarget Symbols | | | | |
| ● Square | 4 | .32 | 4 | .32 |
| ● Horizontal Rectangle | 4 | .32 | 6 | .48 |
| ● Triangle (Point-up) | 5 | .40 | 7 | .56 |
| ● Triangle (Point-down) | 5 | .40 | 7 | .56 |
| ● Snowflake | 5 | .40 | 7 | .56 |
| ● Vertical Light Bar | 7 | .56 | 4 | .32 |
| Fixation Cross | 5 | .40 | 5 | .40 |
| Pattern Mask | 8 | .64 | 7 | .56 |

Note: Viewing distance = 28 in.
Illumination ratio = approximately 4 to 1 (stimulus to background luminance ratio about 27 to 6.8 cd/m$^2$).

TABLE 7

Control Variables: Measured Values for General Transfer Protocols

Velocity Discrimination Protocol

| Stimuli | Visual Angle (Degrees) | Concentric Rings Number | Concentric Rings Width (Degrees) | Expansion Rate (Deg/s) |
|---|---|---|---|---|
| Circle Standard Expansion Rate | 2.8 | 10 | .125 | 1.40 |
| Circle Test Expansion Rates | 2.8 | 10 | .125 | 1.50 |
| | | | | 1.45 |
| | | | | 1.35 |
| | | | | 1.30 |

Note: Viewing distance = 28 inches.

Peripheral Processing Protocol

Red LEDs

- Visual angle: 0.51 degrees
- Number of LEDs: 13 @ 15 degree intervals from 90 degrees left to 90 degrees right of central reference point.
- Number employed experimentally: 3 @ 45 degrees left, 0 degrees, and 45 degrees right.
- Illumination ratio: approximately 99 to 1 (activation to constant luminance ratio about 13.57 to 0.137 cd/$m^2$.)

Note: Viewing distance = 22.5 in.

## Performance Feedback

Performance feedback for the three direct training protocols (target detection, recognition, and identification) was provided upon completion of each training block (20 trials). The percentage of correct responses over the 20 training trials of each training block was displayed in the center of the video monitor during the 1-min interblock rest periods. Feedback was not incorporated into the general transfer protocols (velocity discrimination and peripheral vision two-flash threshold) because performance feedback would have confounded the assessment of general transfer effects.

## Training Regimes

The near-threshold training protocols were conducted in five sessions on five consecutive days. The protocols were organized and administered by training day using computer-controlled programs. Manual intervention was required only to initiate each day's training and to start each protocol following interprotocol rest periods.

The composition of each of the five daily sessions is presented in the experimental design summary appearing in Table 8. These sessions were scheduled on consecutive days; each session lasted approximately 4 hr. The baseline session (Day 1) and post-training assessment session (Day 5) were identical as follows: target detection, 120 trials (20 trials each at 6 visual access SOAs); target recognition, 140 assessment trials (20 trials each at 7 visual access SOAs); and target identification, 160 assessment trials (20 trials each at 8 visual access SOAs). In all, 840 baseline and post-training assessment trials were administered (420 baseline and 420 post-training trials) on the three direct transfer tasks.

The near-threshold training sessions for the target detection, recognition, and identification protocols were conducted on Days 2, 3, and 4, and during the first part of Day 5. A total of 400 training trials, 10 blocks each at 67- and 33-ms visual access times (SOAs), were administered for each direct transfer protocol (target detection, recognition, and identification) on each of three consecutive sessions (Days 2, 3, and 4). On Day 5, 200 training trials were given for each of the three protocols, five blocks each at 67- and 33-ms visual access SOAs. In all, a total of 1400 training trials were completed on each of these protocols; 4200 total trials across all three protocols. The total training exposure for each subject, including baseline, training, and post-training experience, was 5040 trials.

Training was not appropriate on the general transfer protocols; consequently, only baseline and post-training trials were administered (see Table 8). For the velocity discrimination protocol, only two blocks of 20 trials each

TABLE 8

Experimental Design Summary

| Protocol | Training Sessions | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Baseline Day 1 | | | Training Days 2-4 | | | Training Day 5 | | | Post-Training Day 5 | | |
| | B[a] | SOA[b] (ms) | T[c] | B[a] | SOA[b] (ms) | T[c] | B[a] | SOA[b] (ms) | T[c] | B[a] | SOA[b] (ms) | T[c] |
| <u>Specific Transfer Protocols</u> | | | | | | | | | | | | |
| Target Detection | 6 | 17-100 | 120 | 60 | 33/67 | 1200 | 10 | 33/67 | 200 | 6 | 17-100 | 120 |
| Target Recognition | 7 | 17-150 | 140 | 60 | 33/67 | 1200 | 10 | 33/67 | 200 | 7 | 17-150 | 140 |
| Target Identification | 8 | 17-250 | 160 | 60 | 33/67 | 1200 | 10 | 33/67 | 200 | 8 | 17-250 | 160 |
| Specific Transfer Totals | 21 | 17-250 | 420 | 180 | 33/67 | 3600 | 30 | 33/67 | 600 | 21 | 17-250 | 420 |
| <u>General Transfer Protocols</u> | | | | | | | | | | | | |
| Velocity Discrimination | 2 | d | 40 | d | d | d | d | d | d | 2 | d | 40 |
| Peripheral Vision Two-Flash Threshold | 4 | d | 168 | d | d | d | d | d | d | 4 | d | 168 |
| General Transfer Totals | 6 | d | 208 | d | d | d | d | d | d | 6 | d | 208 |

[a]B = Training blocks.

[b]SOA = Stimulus onset asynchrony range. SOAs were administered in increments of 16.7 ms.

[c]T = Training trials.

[d] = Not applicable to indicated protocol.

were required for the baseline and post-training assessments, making a total of 80 trials for each trainee (40 trials on Day 1 for the baseline assessment and 40 trials on Day 5 for the post-training assessment). For the peripheral vision two-flash threshold protocols, four blocks of 42 assessment trials each were administered for both the baseline assessment (Day 1) and the post-training assessment (Day 5). Thus, 168 peripheral vision two-flash threshold trials were accomplished on the baseline assessment, and another 168 trials on the post-training assessment, a total of 336 trials across both assessments.

Daily Routine

The Day 1 routine was organized into two parts. In the first part, trainees received a briefing, orientation, task instructions, and familiarization. Trainees were provided information on the purpose of near-threshold training and specific instructions associated with each direct training and general transfer protocol. After demonstration of the protocols, trainees performed them in a hands-on practice session. The second part of Day 1 focused on the acquisition of baseline data on the three near-threshold direct training protocols and the two general transfer protocols.

Days 2 through 4 were dedicated exclusively to intense training on the three near-threshold, direct training protocols: target detection, recognition, and identification. Day 5 was divided into two parts separated by a 30-minute rest interval. The first part consisted of ten blocks of training on the three near-threshold training protocols. The second part was devoted to the post-training performance assessments for both the direct training and general transfer protocols. The post-training assessments conducted on Day 5 were identical to the baseline assessments accomplished on Day One.

A limited number of warm-up trials were allowed the first time a protocol was administered during a training day. The warm-up trials included no more than ten trials each at the two longest visual access times (SOAs) employed for the particular protocol being administered. The purpose of the warm-up trials was to give the trainees a short period of time to adjust to the unique demands of each protocol. Warm-up trials were not subjected to analysis, nor were they considered in calculating the total training trials administered on each protocol.

Throughout the training sessions, frequent rest periods were provided. The rest periods generally conformed to the following routine: a 1-min, computer-timed relaxation period between each training block (20 trials) and a 10- to 15-min rest period between each training protocol. Refreshments and snacks were available during the longer rest periods.

## Trainees

College-level Air Force Reserve Officer Training Corps (AFROTC) cadets served as trainees. Ten volunteer cadets were selected using the following criteria:

1. Male AFROTC cadets destined for flight training.

2. College-level juniors or seniors physically qualified for flight training as documented by a current flight physical examination (within one year).

3. Special emphasis given to select trainees free from visual defects.

4. Aptitude requirements for flight training satisfied as documented by Air Force Officer Qualifying Test (AFOQT) scores.

5. Participant in AFROTC light aircraft training program (T-41).

6. Strong motivation to be a fighter-attack pilot (self-report).

7. Special emphasis given to select trainees who did not smoke nor use drugs.

8. No alcohol intake permitted throughout the training.

9. Trainee commitment to attend every training session and to complete the entire feasibility investigation.

The ten AFROTC cadets who were selected as trainees met the criteria specified above. The trainees included six college seniors and four juniors, all between the ages of 20 and 24 years (mean age = 21.9 years). Table 9 contains a summary of trainee biographical characteristics.

All ten trainees were either graduates of the AFROTC light aircraft training program or were currently enrolled. Solo flying experience ranged from 5 to 600 hr, with a mean of 128 hr. Four trainees were student pilots with between 5 and 40 hr solo time; five trainees were licensed private pilots, with flying experience ranging from 67 to 206 hr; and one trainee was a licensed instructor pilot with 600 hr flight time.

Trainees were guaranteed anonymity with respect to their performance during the investigation. Names were converted to alphanumeric codes to protect anonymity; only the principal investigator was involved in the conversion process. Trainees were assured that under no circumstances would data associated

TABLE 9

Trainee Biographical Characteristics[a]

| Characteristics | Continuous Data Mean | Range |
|---|---|---|
| Age (years) | 21.9 | 21-24 |
| Height (inches) | 70.8 | 65-74 |
| Weight (pounds) | 166.8 | 140-212 |
| Flight Hours | 128.1 | 5-600 |
| | Categorical Data | |
| College Class | • Seniors: 6<br>• Juniors: 4 | |
| Flight Status | • Instructor Pilot: 1<br>• Private Pilot: 5<br>• Student Pilot: 4 | |
| Handedness | • Right: 8<br>• Left: 2 | |
| Athletic Experience (Highest Level) | • High School Varsity: 5<br>• Collegiate Varsity: 2<br>• No Varsity Experience: 3 | |

[a]Self-reported.

with specific individuals be reported to the Air Force, AFROTC detachment, or any other organization or individual.

A total of about 20 hr of intensive near-threshold training was completed by each of the ten trainees during the investigation. Trainees were paid $8 per hr for their participation. Full payment was made upon completion of the training.

## Data Analysis

The training paradigm used in the present study interposed intensive near-threshold training sessions between baseline and post-training assessments. Incorporated within this framework were repeated measures of training progress. Over the duration of the training, the same trainees were subjected to baseline, training, and post-training assessments on the near-threshold training protocols as well as baseline and post-training assessments on the general transfer protocols.

A repeated measures analysis of variance (ANOVA) model served as the central data analysis model. This ANOVA is designed for situations in which repeated assessments (e.g., baseline, training, and post-training assessments) are made on the same individual. Consequently, a single factor (training effects), fixed-constants, ANOVA model with repeated measures on the same elements was selected (Winer, 1962). A variation of this model was used for further analysis of the peripheral vision two-flash threshold data (Bruning & Kintz, 1968).

Data acquisition was geared to support the requirements of the single-factor, repeated measures ANOVA model. Computer-controlled data acquisition permitted coordination, integration, and recording of significant training events and data on each trial. Event timing, interevent intervals, and response actions were chronicled accordingly. Learning curve data, performance metrics, and data analysis formats were easily derived.

# RESULTS

The near-threshold training results are addressed in the following sequence: (a) group learning curves; (b) trainee performance differences; (c) comparison of baseline and post-training performance; and (d) general transfer of training.

## Group Learning Curves

The descriptive statistics associated with the trainee group learning curves are contained in Table 10. This table indicates the group mean, standard deviation, and range of

scores for each segment of training in target detection, recognition, and identification at both 67 and 33 ms. Group learning curves are presented for composite performance in target detection, recognition, and identification (Figure 6) and for target identification performance alone (Figure 7). The learning curves were plotted by baseline and major training segment; each segment consisted of 100 training trials.

Two learning curves are plotted for both Figures 6 and 7: one curve for training performance on trials with a visual access time of 67 ms and one curve for trials with a visual access time of 33 ms. Performance is plotted as a function of percent correct responses (mean of 10 trainees) across the baseline and seven training segments of 100 trials each. The seven training segments represented a total of 700 trials at 67-ms and 700 trials at 33-ms visual access time. Baseline performance is shown as the first data point at the far left of each figure.

As is evident from Figures 6 and 7, performance increased with training repetitions. The rate of performance increase, however, diminished as stimulus (target/non-target) visual access time was reduced. Moreover, the performance level attained at the time the training was terminated was higher at 67-ms visual access time than it was at 33 ms. The steepness of the learning curves across the seven training segments also emphasizes the greater difficulty of training at 33 ms vis-a-vis 67 ms.

The group data were subjected to a more detailed analysis which is reported separately (Secrist & Hartman, 1993b). This detailed analysis examines the group training effects more closely to better understand the relationship between training efficacy and training time. Differences between training protocols, visual access times, training time history, and related interactions are also addressed in the cited article.

Trainee Performance Differences

Substantial differences were found in individual trainability and performance. Differences in training effects were especially pronounced at visual access times of 50 and 33 ms. Indeed, the data suggest that 50 ms may be a critical benchmark in differentiating inherent near-threshold information acquisition and processing ability or aptitude. Moreover, performance at 50-ms visual access time may prove to be an important predictor of both training time to criterion and ultimate skill level.

Figures 8 and 9 provide typical examples of individual training effects at 33-ms visual access time. Each figure represents an example of differences in both baseline capability and learning rate on two difficult protocols. In

TABLE 10

**Performance Accuracy at 67 and 33 Milliseconds: Correct Responses by Training Segment (n = 10)**

| Protocol | Training Segment[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI | VII |
| **Target Detection (67 ms)** | | | | | | | |
| Mean | 93.7 | 97.7 | 98.7 | 99.4 | 99.7 | 99.7 | 99.3 |
| SD | 6.6 | 3.2 | 1.4 | 1.4 | 0.7 | 0.7 | 1.9 |
| Range | 82-100 | 90-100 | 96-100 | 96-100 | 98-100 | 98-100 | 94-100 |
| **Target Recognition (67 ms)** | | | | | | | |
| Mean | 96.4 | 96.4 | 99.1 | 99.3 | 99.4 | 99.3 | 99.7 |
| SD | 4.3 | 4.8 | 1.5 | 1.5 | 0.8 | 1.1 | 0.5 |
| Range | 88-100 | 87-100 | 95-100 | 96-100 | 98-100 | 97-100 | 99-100 |
| **Target Identification (67 ms)** | | | | | | | |
| Mean | 95.0 | 95.9 | 98.7 | 97.8 | 98.4 | 97.5 | 99.6 |
| SD | 5.9 | 6.3 | 1.0 | 4.0 | 2.7 | 4.8 | 1.0 |
| Range | 84-100 | 81-100 | 97-100 | 87-100 | 93-100 | 85-100 | 97-100 |
| **Target Detection (33 ms)** | | | | | | | |
| Mean | 73.6 | 80.6 | 84.1 | 86.1 | 87.4 | 90.3 | 86.0 |
| SD | 15.3 | 18.5 | 13.8 | 13.1 | 11.9 | 13.8 | 15.5 |
| Range | 47-92 | 48-99 | 55-100 | 55-100 | 66-100 | 54-100 | 50-100 |
| **Target Recognition (33 ms)** | | | | | | | |
| Mean | 71.3 | 74.6 | 76.2 | 81.7 | 84.5 | 86.8 | 85.7 |
| SD | 14.5 | 14.2 | 12.9 | 12.8 | 12.3 | 11.5 | 10.1 |
| Range | 46-91 | 51-92 | 56-93 | 59-98 | 58-98 | 66-99 | 65-96 |
| **Target Identification (33 ms)** | | | | | | | |
| Mean | 54.9 | 59.5 | 64.4 | 66.3 | 70.5 | 73.4 | 74.0 |
| SD | 18.3 | 17.2 | 17.4 | 18.0 | 19.2 | 18.9 | 16.5 |
| Range | 28-78 | 32-80 | 43-92 | 40-94 | 45-99 | 42-98 | 41-95 |

[a]Training Segment represents 100 training trials.

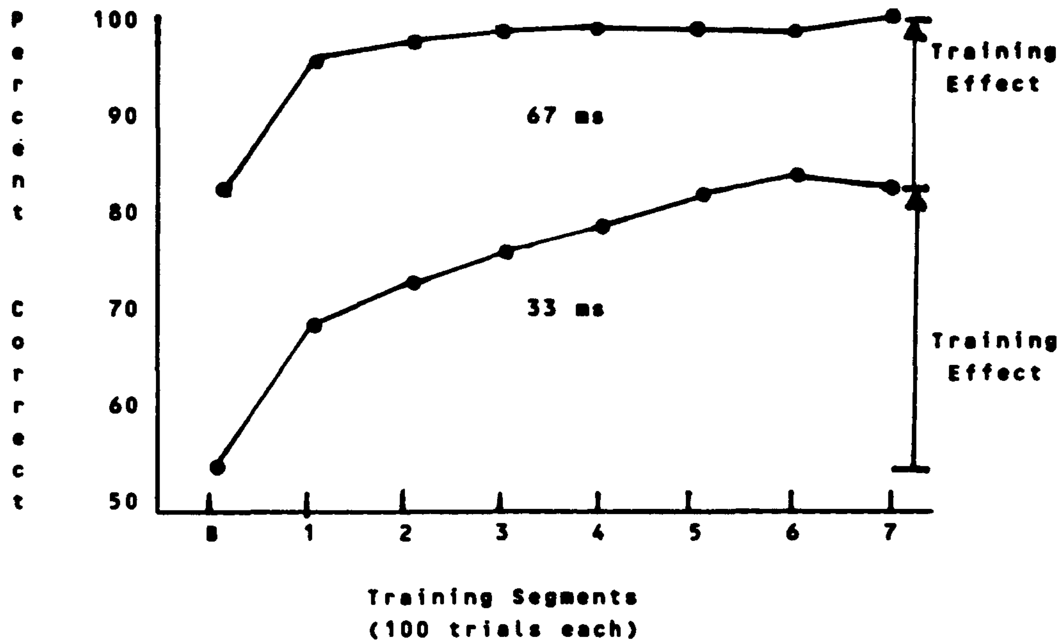



Figure 6. Composite performance in target detection, recognition, and identification. Group means plotted for baseline (B) and each training segment (n = 10).

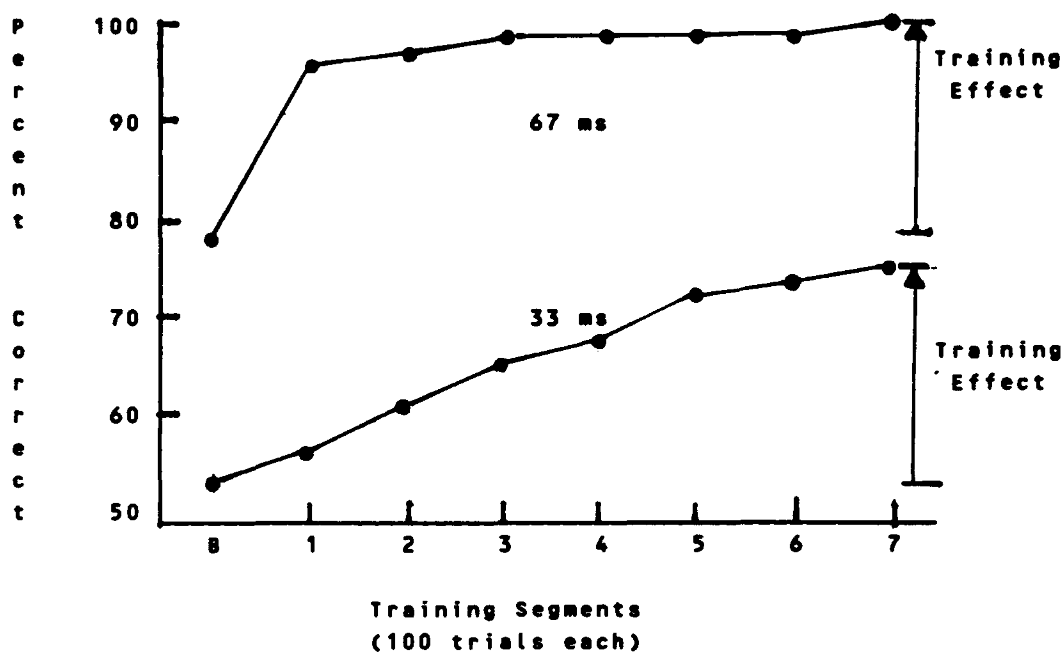



Figure 7. Target identification performance. Group means plotted for baseline (B) and each training segment (n = 10).

Figure 8, for example, two trainees exhibit markedly different baseline capacities, yet somewhat similar learning rates. Despite this disparity in baseline capability, Trainees $G_3$ and $P_2$ showed consistent improvement over the course of the training. Eventually, Trainee $G_3$ attained a target recognition performance of over 95 percent accuracy, while Trainee $P_2$ consistently improved to a performance level of 81 percent accuracy.

Pronounced individual differences in target identification performance (33-ms visual access time) are portrayed in Figure 9. The rapid learning rate and superior performance of Trainee $S_1$ is in sharp contrast to the difficult, painstakingly slow learning experience of Trainee $P_3$. The training effect for Trainee $P_3$ reached a critical mass at about the sixth training segment (600 trials), and he began to show significant improvement in performance when the training ended. Trainee $S_1$, on the other hand, attained a performance level of 92 percent in target identification accuracy by the end of the third training segment (300 trials), achieving an extraordinarily high level of target identification accuracy on the remaining four segments: 94 percent, 99 percent, 98 percent, and 95 percent, respectively. The exceptional performance of Trainee $S_1$ was also manifested at 67-ms target duration where he completed <u>1300 consecutive target detection, recognition, and identification trials without a single error.</u>

Additional analysis of individual differences in learning rate and performance reveals considerable diversity. Trainee $G_1$ achieved near errorless target detection performance at both 67- and 33-ms visual access times (see Figure 10). This performance is noteworthy in two respects: (a) the rate of performance improvement (99 percent by the end of the second training segment), and (b) the learning curve at 33-ms visual access time is as steep as it is for 67-ms visual access time.

Next, examples of individual differences in learning rate and performance will focus on the most difficult training protocol, target identification. Figure 11 portrays a trainee ($G_3$) with a substantial difference in initial learning rate at 67- versus 33-ms visual access time. By the seventh training segment, however, performance at 33-ms target duration was climbing sharply toward the level attained at 67-ms visual access time. With respect to individual differences, contrast the smooth learning curve and consistent training performance of trainee $G_1$ (Figure 10) with the uneven learning curve and inconsistent performance of Trainee $G_3$ (Figure 11).

Figure 12 characterizes a trainee ($S_3$) who performed at 100 percent target identification accuracy at 67-ms temporal duration on the baseline assessment and essentially maintained

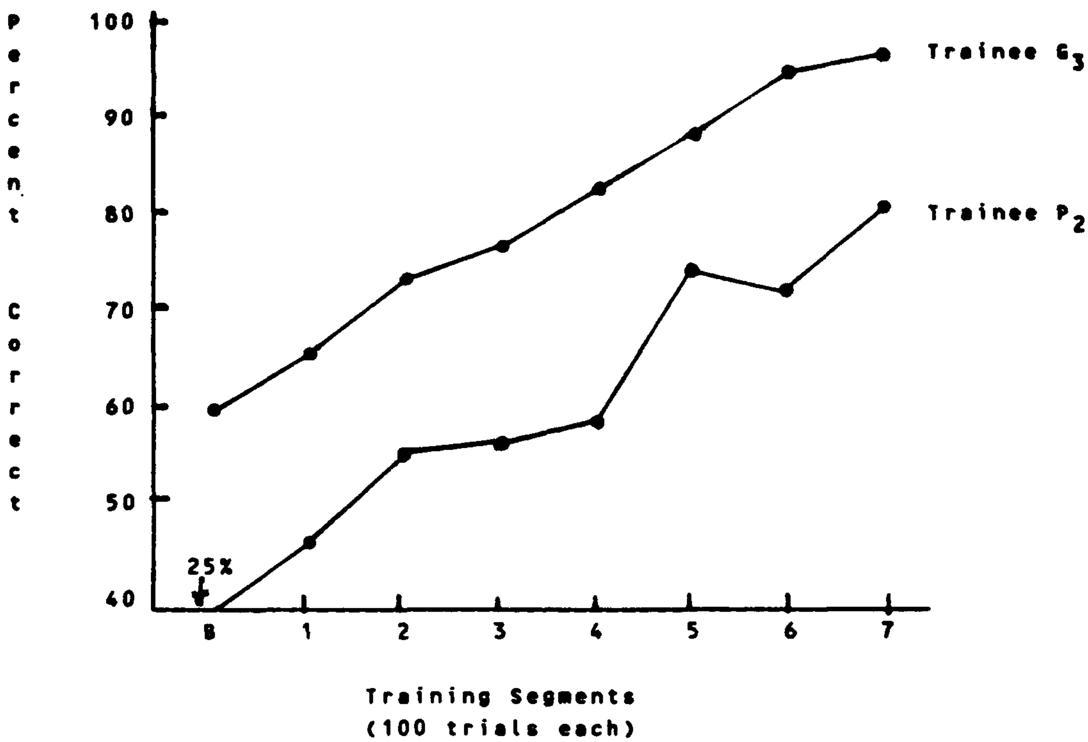



Figure 8. Target recognition learning curves for Trainees $G_3$ and $P_2$ at 33-ms visual access time.

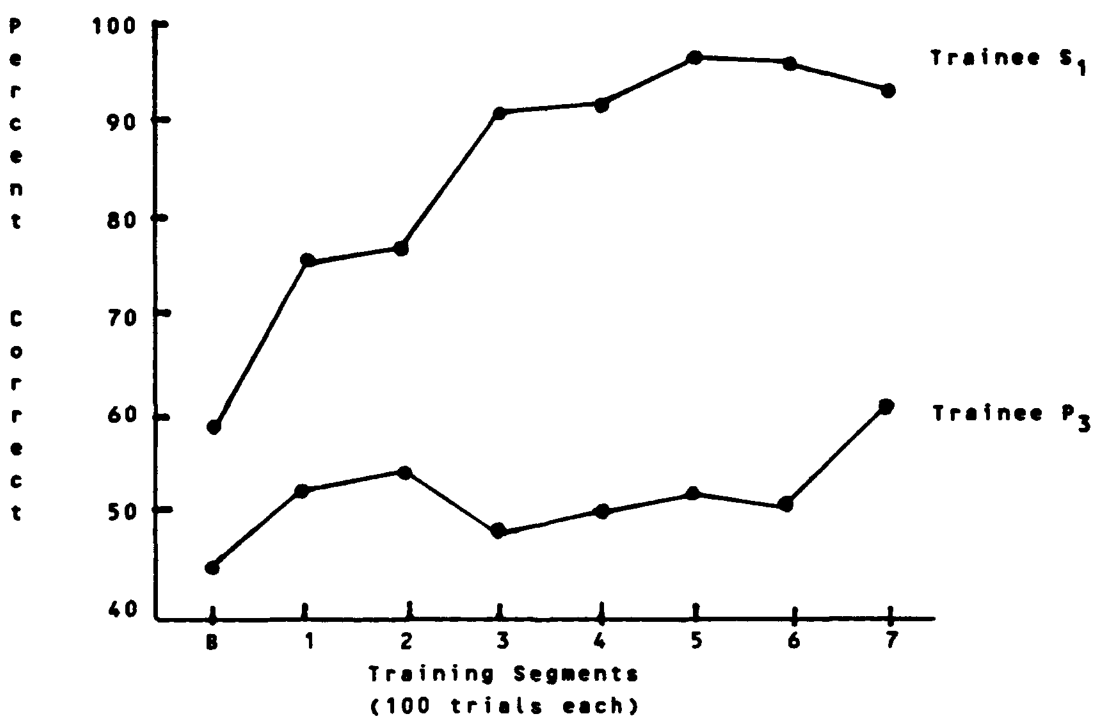



Figure 9. Target identification learning curves for Trainees $S_1$ and $P_3$ at 33-ms visual access time.

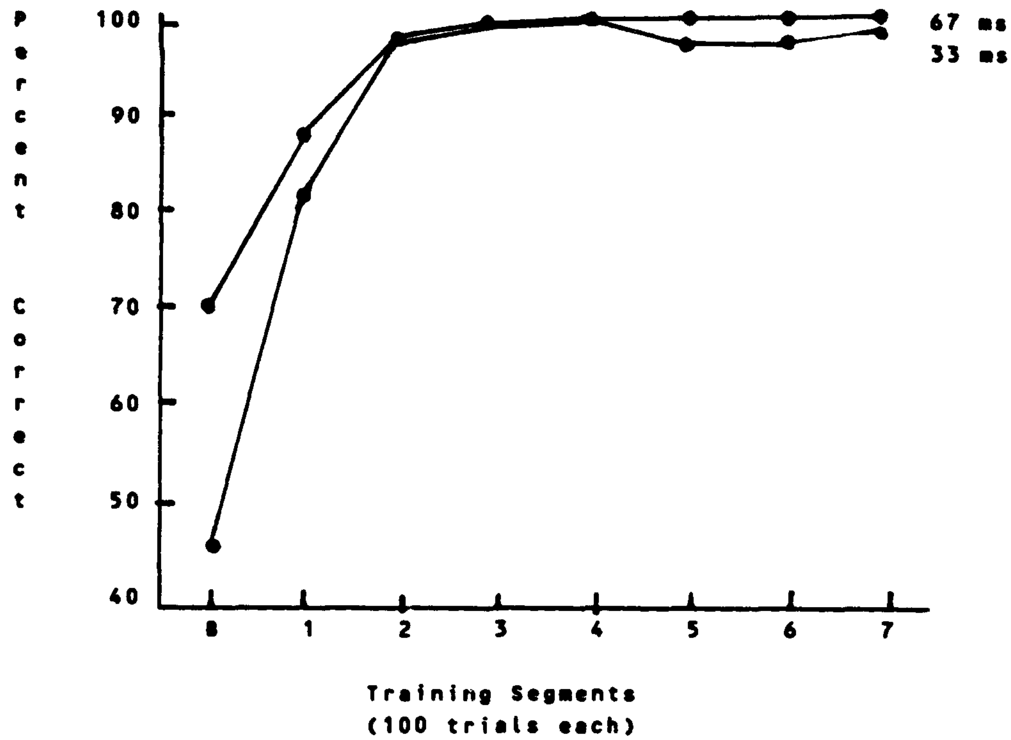



Figure 10. Target detection learning curves for Trainee $G_1$ at 67-and 33-ms visual access times.

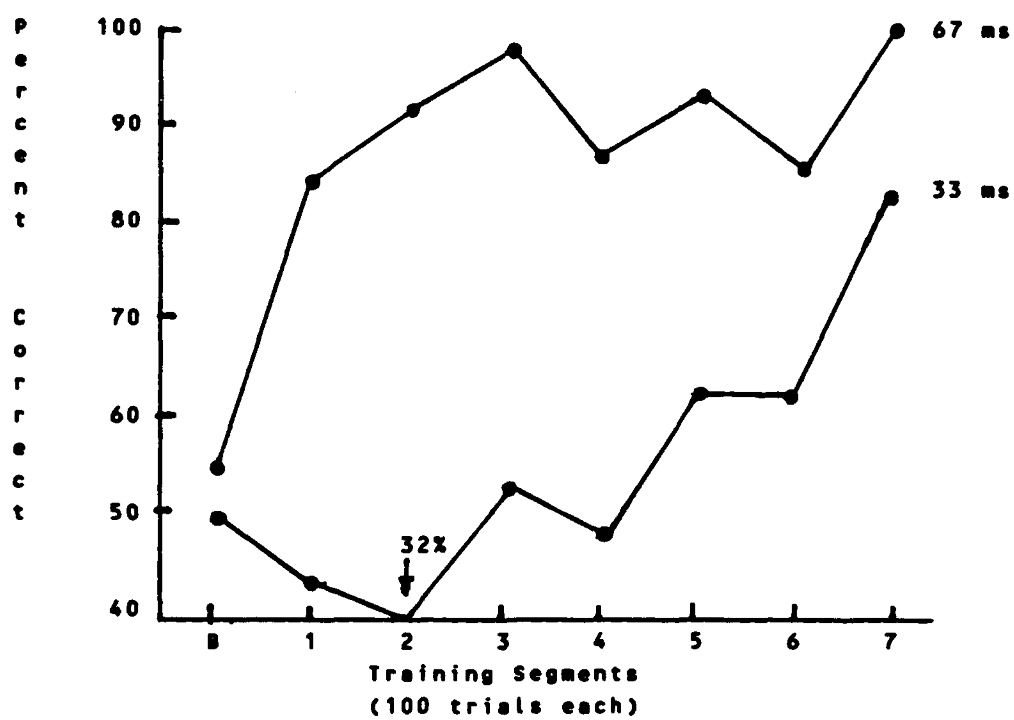



Figure 11. Target identification learning curves for Trainee $G_3$ at 67-and 33-ms visual access times.

this exceptional level of performance during the course of training. A much lower target identification accuracy baseline was manifested at the 33-ms visual access time. However, task performance at the more challenging temporal duration of 33 ms quickly improved until a level of 93 percent target identification accuracy was reached during the sixth training segment.

Figure 13 illustrates the rather unstable learning and marginal performance of Trainee $P_1$. Although a high level of performance was attained for target identification accuracy at 67 ms, no improvement in accuracy at 33 ms was found by the end of the seven training sessions. In fact, target identification accuracy was lower at the end of training than it was on the baseline assessment (50 percent versus 41 percent). Trainee $P_1$ produced little evidence that he could accurately acquire and process brief target cues (less than 50 ms). Of particular interest here is implicit differential ability or aptitude; for example, as suggested by Trainees $G_1$ and $P_1$ (compare Figures 10 and 13).

Table 11 summarizes the individual differences data. The first part of Table 11 contains a rank-order listing of the ten trainees based on composite performance across all seven training segments of the target detection, recognition, and identification protocols combined. This composite performance score is based on 4200 training trials at both 67- and 33-ms temporal durations. *The composite score reflects the number* and percentage of correct responses for each trainee out of the 4200 training trials administered.

The second part of Table 11 provides a similar rank-order of the ten trainees based on performance on the most difficult protocol: target identification at 33-ms visual access time. As indicated earlier, in this protocol trainees discriminate between ten visual-spatial forms and decide on one of five response options based on information present for only 33 ms. Table 11 reflects the number and percentage of targets correctly identified by each trainee out of 700 target identification training trials. Individual differences in performance on this particular training protocol are readily apparent.

## Baseline Versus Post-Training Performance

Another way of evaluating the near-threshold training data is to examine differences between baseline and post-training performance on the target detection, recognition, and identification protocols at each of six SOAs (100, 83, 67, 50, 33, and 17 ms). Table 12 (page 41) contains the descriptive statistics for both baseline and post-training performance assessments on these three protocols. Mean scores, standard deviations, and ranges are shown for the six temporal durations (SOAs).

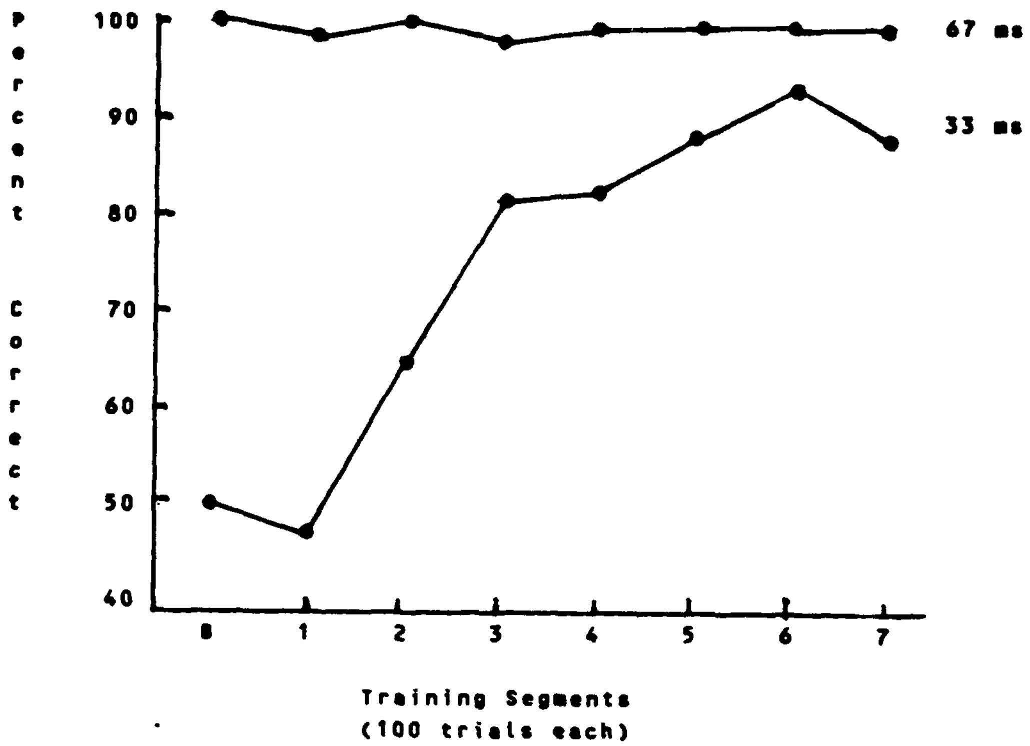



Figure 12. Target identification learning curves for Trainee $S_3$ at 67–and 33–ms visual access times.

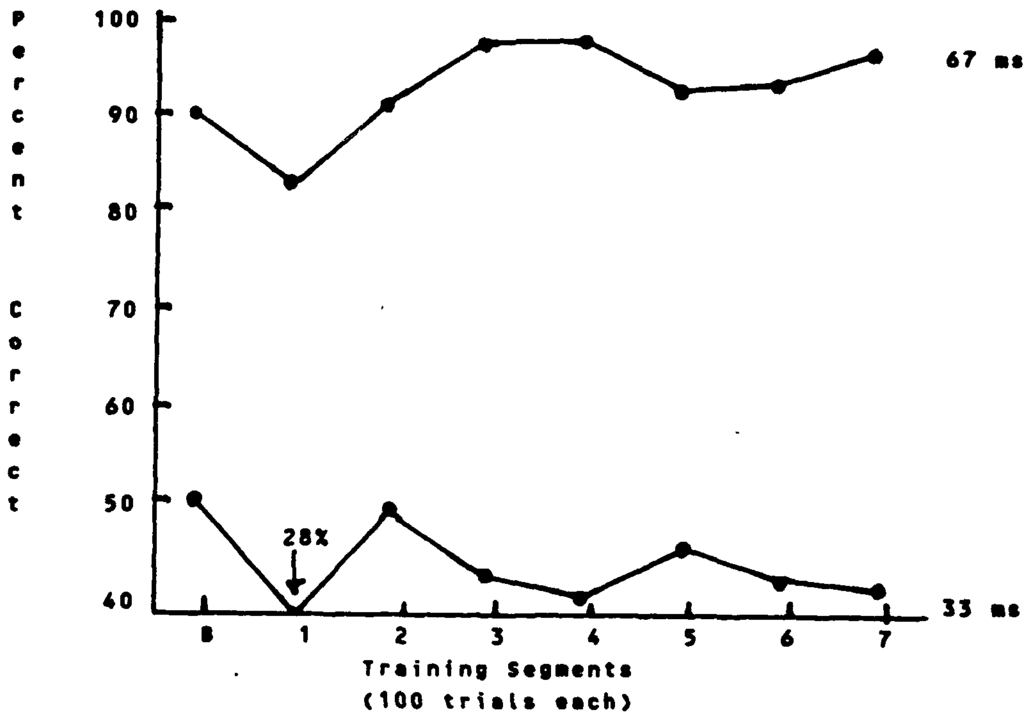



Figure 13. Target identification learning curves for Trainee $P_1$ at 67–and 33–ms visual access times.

TABLE 11

Individual Differences in Trainee Performance

| Trainee Rank-Order | Total Score | Percent |
|---|---|---|
| Composite Performance[a] | | |
| $S_1$ | 4054 | 97 |
| $G_1$ | 3914 | 93 |
| $S_3$ | 3908 | 93 |
| $S_2$ | 3865 | 92 |
| $G_2$ | 3827 | 91 |
| $P_3$ | 3611 | 86 |
| $G_4$ | 3608 | 86 |
| $G_3$ | 3557 | 85 |
| $P_2$ | 3294 | 78 |
| $P_1$ | 3074 | 73 |
| Performance on Most Difficult Protocol[b] | | |
| $S_1$ | 634 | 91 |
| $S_2$ | 578 | 83 |
| $S_3$ | 548 | 78 |
| $G_1$ | 545 | 78 |
| $G_2$ | 521 | 74 |
| $G_4$ | 394 | 56 |
| $G_3$ | 385 | 55 |
| $P_3$ | 377 | 54 |
| $P_2$ | 360 | 51 |
| $P_1$ | 288 | 41 |

[a]Composite training performance score based on 4200 target detection, recognition, and identification training trials at both 67- and 33-ms visual access times.

[b]Target identification protocol based on 700 trials at 33-ms visual access time. Involves discrimination decisions on 10 visual spatial symbols and 5 control options.

A graphic profile of group baseline and post-training composite performance is presented in bargraph format in Figure 14. Composite performance represents combined target detection, recognition, and identification performance. As shown in Figure 14, post-training performance was substantially higher than baseline performance at every temporal duration except 17 ms.

The impact of near-threshold training is clearly evident in Table 12 and Figure 14. In nearly every case, post-training mean performance is higher and performance variability lower in comparison with the baseline performance. A single-factor, repeated measures ANOVA was carried out to determine if these differences are statistically significant.

The ANOVA results on differences in target detection baseline and post-training performance are highly significant ($p < .01$) at all SOAs except 17 ms (Table 13). The ANOVA on the target recognition data indicated that baseline and post-training performance differences are statistically significant well beyond the 0.01 level for the 33-, 50-, and 67-ms temporal durations (see Table 14). The differences at the other visual access times did not reach statistical significance at the 0.01 level; however, in all cases, the mean performance differences were in the expected direction (higher post-training performance levels). The ANOVA on the target identification performance shows that baseline and post-training differences are strongly significant ($p < 0.01$) at the 33-, 50-, and 67-ms visual access times (see Table 15). The performance changes at the other temporal durations are also in the expected direction (post-training performance higher), but these differences did not reach statistical significance at the 0.01 level. It should be noted that the significant differences for target recognition and identification were found at the two SOAs (33 and 67 ms) used during the 4200 trial training regimen and the one temporal duration equidistant between the two training SOAs.

The consistency of the positive training effects across the combined target detection, recognition, and identification protocols is evident from an examination of Table 16. This table shows the percentage increase in performance from pre-training to post-training assessments at two temporal durations: 33-ms visual access time, the briefest training SOA; and 50-ms visual access time, a benchmark SOA that appeared to differentiate superior performers from other trainees. Table 16 indicates that group composite performance (target detection, recognition, and identification accuracy) improved 43 percent at 50-ms and 52 percent at 33-ms target duration, while individual performance increases ranged from near 0 to 136 percent improvement.

TABLE 12

**Comparative Performance at Six Visual Access Times: Baseline Vs. Post-Training (n = 10)**

| Visual Access Time[a] (SOA in ms) | Comparative Performance[b] Target Detection Mean | SD | Range | Target Recognition Mean | SD | Range | Target Identification Mean | SD | Range |
|---|---|---|---|---|---|---|---|---|---|
| 100 ms | | | | | | | | | |
| Baseline | 15.9 | 3.6 | 10-20 | 18.2 | 2.1 | 14-20 | 18.4 | 1.4 | 16-20 |
| Post-Training | 20.0 | 0 | 20-20 | 19.9 | 0.3 | 19-20 | 19.9 | 0.3 | 19-20 |
| 83 ms | | | | | | | | | |
| Baseline | 15.8 | 3.8 | 9-20 | 17.5 | 3.2 | 10-20 | 18.7 | 1.4 | 16-20 |
| Post-Training | 20.0 | 0 | 20-20 | 19.9 | 0.3 | 19-20 | 19.9 | 0.3 | 19-20 |
| 67 ms | | | | | | | | | |
| Baseline | 16.4 | 2.8 | 13-20 | 17.0 | 2.4 | 12-19 | 15.6 | 3.2 | 11-20 |
| Post-Training | 20.0 | 0 | 20-20 | 20.0 | 0 | 20-20 | 19.8 | 0.6 | 18-20 |
| 50 ms | | | | | | | | | |
| Baseline | 15.1 | 3.3 | 8-19 | 12.9 | 4.0 | 5-17 | 13.0 | 5.4 | 3-18 |
| Post-Training | 19.9 | 0.3 | 19-20 | 19.2 | 1.1 | 17-20 | 19.5 | 1.3 | 6-20 |
| 33 ms | | | | | | | | | |
| Baseline | 10.7 | 3.5 | 4-15 | 10.6 | 2.9 | 5-14 | 10.5 | 1.4 | 9-13 |
| Post-Training | 16.8 | 3.6 | 9-20 | 16.6 | 3.0 | 11-20 | 14.8 | 3.3 | 8-19 |
| 17 ms | | | | | | | | | |
| Baseline | 12.3 | 3.3 | 6-16 | 9.3 | 3.1 | 4-14 | 6.0 | 3.2 | 1-10 |
| Post-Training | 10.0 | 2.5 | 6-13 | 10.4 | 2.3 | 7-15 | 6.5 | 2.5 | 2-10 |

[a]Visual access time measured by stimulus onset asynchrony (SOA) in milliseconds.

[b]Correct responses by protocol and SOA; 20 trials at each SOA.

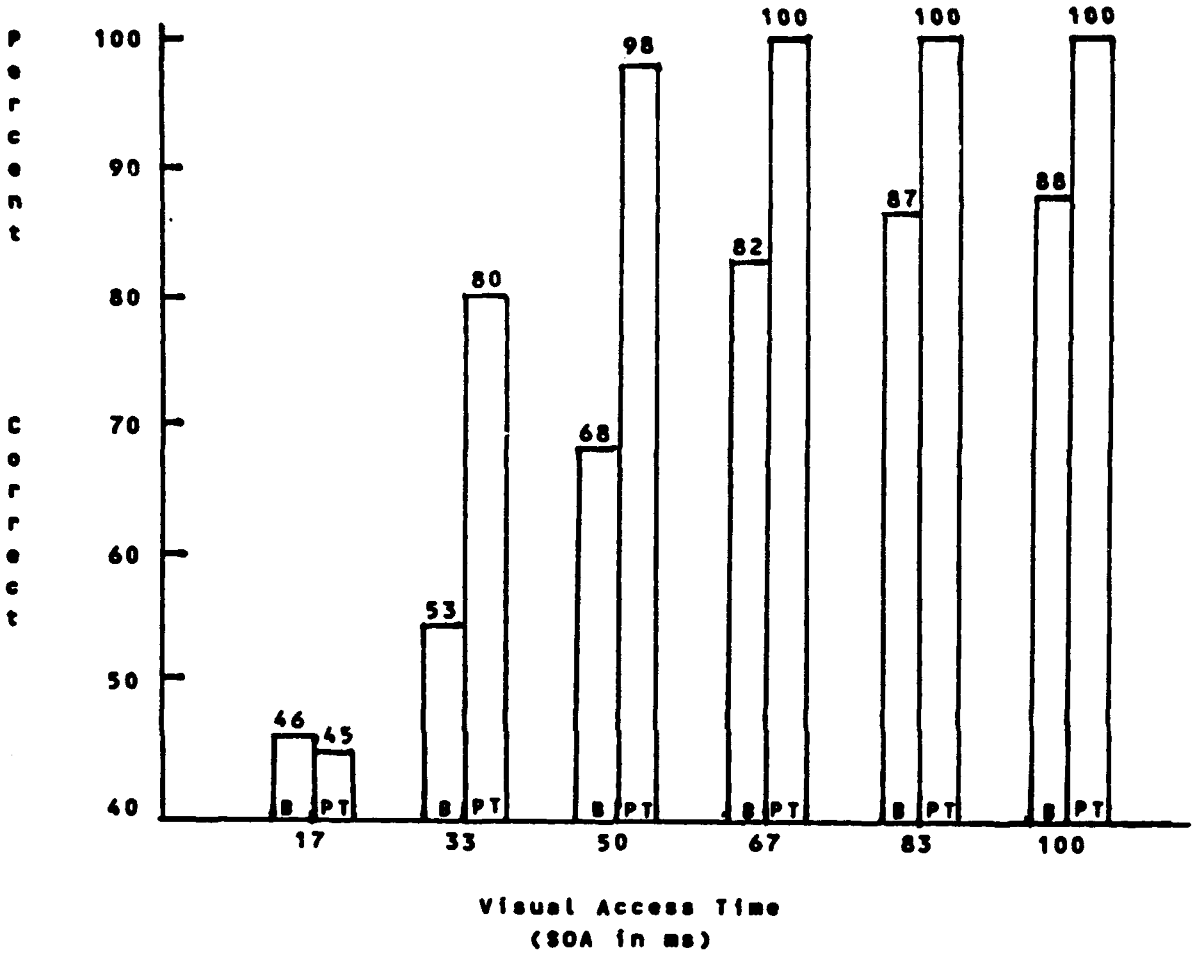



Figure 14. Group composite performance (target detection, recognition, and identification): Baseline (B) vs. post-training (PT). Group n = 10; 200 trials per SOA.

TABLE 13

Target Detection ANOVA: Baseline (B) vs. Post-Training (PT) Performance

ANOVA Summary[a]

| Source of Variance | SS | df | MS | F |
|---|---|---|---|---|
| Between Trainees | 223.08 | 9 | | |
| Within Trainees | 1999.25 | 110 | | |
| Training Effects | 1425.83 | 11 | 129.62 | 22.38*** |
| Error | 573.42 | 99 | 5.79 | |
| Total | 2222.33 | 119 | | |

A priori Comparisons[b]

| SOA (ms)[c] | B | PT | $SS_c$ | $MS_{error}$ | F |
|---|---|---|---|---|---|
| 100 | 159 | 200 | 84.05 | 5.79 | 14.52** |
| 83 | 158 | 200 | 88.20 | 5.79 | 15.23** |
| 67 | 164 | 200 | 64.80 | 5.79 | 11.19** |
| 50 | 151 | 199 | 115.20 | 5.79 | 19.90** |
| 33 | 107 | 168 | 186.05 | 5.79 | 32.13** |
| 17 | 123 | 100 | 26.45 | 5.79 | 4.57 |

*** $F_{.999}$ (11, 99) = 3.25
** $F_{.99}$ (1, 99) = 6.93

[a]Single-factor repeated measures ANOVA.
[b]Comparisons planned prior to inspection of data.
[c]SOA in milliseconds.

TABLE 14

Target Recognition ANOVA: Baseline (B) vs. Post-Training (PT) Performance

ANOVA Summary[a]

| Source of Variance | SS | df | MS | F |
|---|---|---|---|---|
| Between Trainees | 199.54 | 9 | | |
| Within Trainees | 2227.25 | 110 | | |
| Training Effects | 1801.09 | 11 | 163.74 | 38.04*** |
| Error | 426.16 | 99 | 4.30 | |
| Total | 2426.79 | 119 | | |

A priori Comparisons[b]

| SOA (ms)[c] | B | PT | $SS_c$ | $MS_{error}$ | F |
|---|---|---|---|---|---|
| 100 | 182 | 199 | 14.45 | 4.30 | 3.36 |
| 83 | 175 | 199 | 28.80 | 4.30 | 6.70 |
| 67 | 170 | 200 | 45.00 | 4.30 | 10.47** |
| 50 | 129 | 192 | 198.45 | 4.30 | 46.15** |
| 33 | 106 | 166 | 180.00 | 4.30 | 41.86** |
| 17 | 93 | 104 | 6.05 | 4.30 | 1.41 |

*** $F_{.999}$ (11, 99) = 3.25
** $F_{.99}$ (1, 99) = 6.93

[a]Single-factor repeated measures ANOVA.
[b]Comparisons planned prior to inspection of data.
[c]SOA in milliseconds.

TABLE 15

Target Identification ANOVA: Baseline (B) vs. Post-Training (PT) Performance

ANOVA Summary[a]

| Source of Variance | SS | df | MS | F |
|---|---|---|---|---|
| Between Trainees | 236.70 | 9 | | |
| Within Trainees | 3373.67 | 110 | | |
| Training Effects | 2938.97 | 11 | 267.18 | 60.85*** |
| Error | 434.70 | 99 | 4.39 | |
| Total | 3610.37 | 119 | | |

A priori Comparisons[b]

| SOA (ms)[c] | B | PT | $SS_c$ | $MS_{error}$ | F |
|---|---|---|---|---|---|
| 100 | 184 | 199 | 11.25 | 4.39 | 2.56 |
| 83 | 187 | 199 | 7.20 | 4.39 | 1.64 |
| 67 | 156 | 198 | 88.20 | 4.39 | 20.19** |
| 50 | 130 | 195 | 211.25 | 4.39 | 48.12** |
| 33 | 105 | 148 | 92.45 | 4.39 | 21.06** |
| 17 | 60 | 65 | 1.25 | 4.39 | 0.28 |

*** $F_{.999}(11, 99) = 3.25$
** $F_{.99}(1, 99) = 6.93$

[a]Single-factor repeated measures ANOVA.
[b]Comparisons planned prior to inspection of data.
[c]SOA in milliseconds.

TABLE 16

**Composite Performance Improvement at 50- and 33-Millisecond Visual Access Times (SOA): Baseline (B) vs. Post-Training (PT)**

| Trainees and Visual Access Times | Composite Score[a] B | PT | Percentage Change |
|---|---|---|---|
| $P_2$ | | | |
| 50 ms | 25 | 59 | +136 |
| 33 ms | 18 | 41 | +128 |
| $G_3$ | | | |
| 50 ms | 30 | 59 | +97 |
| 33 ms | 35 | 51 | +46 |
| $G_2$ | | | |
| 50 ms | 35 | 54 | +54 |
| 33 ms | 36 | 51 | +42 |
| $S_3$ | | | |
| 50 ms | 44 | 60 | +37 |
| 33 ms | 35 | 59 | +69 |
| $G_1$ | | | |
| 50 ms | 44 | 58 | +31 |
| 33 ms | 31 | 54 | +74 |
| $G_4$ | | | |
| 50 ms | 46 | 60 | +30 |
| 33 ms | 32 | 49 | +53 |
| $P_1$ | | | |
| 50 ms | 41 | 52 | +27 |
| 33 ms | 29 | 28 | -3 |
| $S_1$ | | | |
| 50 ms | 50 | 60 | +20 |
| 33 ms | 38 | 58 | +53 |
| $P_3$ | | | |
| 50 ms | 42 | 60 | +19 |
| 33 ms | 24 | 42 | +75 |
| $S_2$ | | | |
| 50 ms | 53 | 60 | +13 |
| 33 ms | 40 | 49 | +23 |
| Group (n = 10) | | | |
| 50 ms | 41.0 | 58.6 | +43 |
| 33 ms | 31.8 | 48.2 | +52 |

[a]Composite score is total correct responses for target detection, recognition, and identification out of 60 baseline (B) trials vs. 60 post-training (PT) trials.

## General Transfer of Training

The general transfer of training data reflect the extent that intensive near-threshold training in target detection, recognition, and identification enhanced performance on two different perceptual-cognitive tasks that are, at least, partly dependent on near-threshold capability. The target detection, recognition, and identification protocols emphasized foveal vision information uptake and associated perceptual-cognitive processing. One general transfer protocol, velocity discrimination, also operates on foveal vision information, but has somewhat dissimilar perceptual-cognitive demands. The protocol for peripheral vision two-flash threshold, on the other hand, seems to be more congruent in perceptual-cognitive processing demands, but with a different locus of information uptake (visual periphery rather than the fovea).

Table 17 contains the descriptive statistics for the two general transfer protocols (velocity discrimination and peripheral vision two-flash threshold). Mean scores, standard deviations, and range data are presented for the baseline measurements and the similar assessments that followed the near-threshold training. An inspection of Table 17 shows the highly consistent nature of the data. Performance on all post-training measures is higher than performance on the corresponding pre-training assessments.

Figure 15 graphically illustrates baseline and post-training measures of velocity discrimination and peripheral vision two-flash threshold, including the block and eccentricity assessments. Tables 18 and 19 present the ANOVA to test the statistical significance of differences in the general transfer protocol baseline and post-training comparative assessments.

Although post-training performance exceeds baseline performance on both velocity discrimination assessment blocks, these differences fail to reach statistical significance at the 0.05 level (see Table 18). The two-flash threshold statistical data indicate that the differences in baseline and post-training performance are statistically significant on both the assessment blocks and eccentricity measures (see Table 19). Since no training occurred on the peripheral vision two-flash threshold task during the intervening period, it is at least suggestive that this improvement might have resulted from a strengthening of perceptual and cognitive processes involved in near-threshold information acquisition and processing.

Group baseline vis-a-vis post-training performance improved an average of 18 percent on the two-flash threshold assessment blocks and 20 percent on the eccentricity measures

TABLE 17

General Transfer of Training Performance: Baseline (B) vs. Post-Training (PT)

Velocity Discrimination Performance[a] (n = 10)

| Block[b] | Mean | | Standard Deviation | | Range | |
|---|---|---|---|---|---|---|
| | B | PT | B | PT | B | PT |
| 1 | 14.3 | 15.0 | 1.8 | 2.2 | 12-17 | 13-19 |
| 2 | 15.6 | 16.0 | 1.3 | 2.6 | 14-17 | 13-20 |

Two-Flash Threshold Performance[a] (n = 9)

| Measure | Mean | | Standard Deviation | | Range | |
|---|---|---|---|---|---|---|
| | B | PT | B | PT | B | PT |
| Block[c] | | | | | | |
| 1 | 26.9 | 29.7 | 4.9 | 4.2 | 21-35 | 25-36 |
| 2 | 29.7 | 35.1 | 2.7 | 4.0 | 27-36 | 30-42 |
| 3 | 26.8 | 33.9 | 6.4 | 4.9 | 17-36 | 29-42 |
| 4 | 29.2 | 34.6 | 4.7 | 5.2 | 20-35 | 28-42 |
| Eccentricity[d] | | | | | | |
| L-45$^{o}$ | 37.2 | 45.2 | 8.6 | 5.3 | 21-51 | 37-53 |
| R+45$^{o}$ | 39.6 | 46.8 | 8.7 | 8.8 | 26-51 | 31-56 |

[a]Correct responses per block
[b]Block = 20 trials
[c]Block = 42 trials
[d]Block = 56 trials

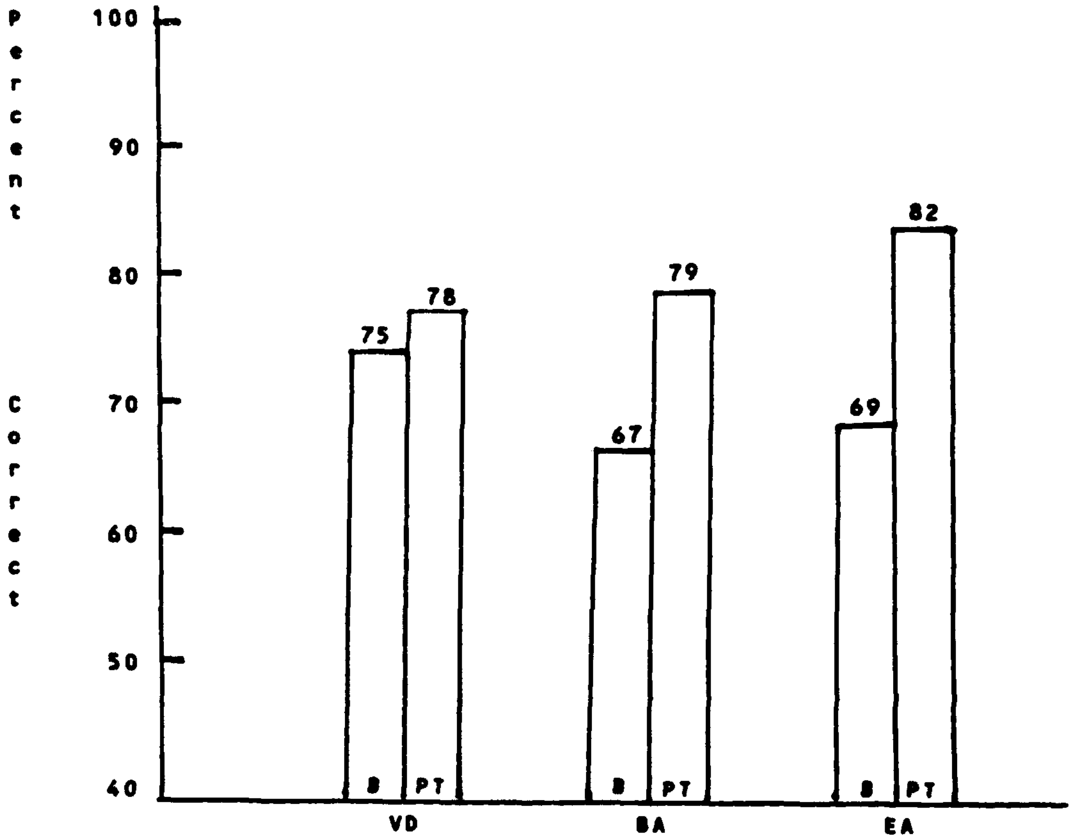



Figure 15. General transfer of training. Baseline (B) vs. post-training (PT) performance for velocity discrimination (VD) and for peripheral vision two-flash threshold block assessments (BA) and eccentricity assessments (EA). VA: n = 10, trials = 40. BA: n = 9, trials = 168. EA: n = 9, trials = 112.

TABLE 18

Velocity Discrimination ANOVA: Baseline vs. Post-Training Performance

ANOVA Summary[a]

| Source of Variance | SS | df | MS | F |
|---|---|---|---|---|
| Between Trainees | 46.73 | 9 | | |
| Within Trainees | 118.25 | 30 | | |
| Training Effects | 16.48 | 3 | 5.49 | 1.46 |
| Error | 101.77 | 27 | 3.77 | |
| Total | 164.98 | 39 | | |

* $F_{.95}$ (3, 27) = 2.97

[a]Single-factor repeated measures ANOVA.

TABLE 19

Peripheral Vision Two-Flash Threshold ANOVA

| Baseline vs. Post-Training Assessment Blocks | | | | |
|---|---|---|---|---|
| Source of Variance | SS | df | MS | F |
| Between Trainees | 379.90 | 8 | | |
| Within Trainees | 1750.50 | 63 | | |
| General Transfer Effects | 708.36 | 7 | 101.2 | 5.44*** |
| Error | 1042.14 | 56 | 18.6 | |
| Total | 2130.40 | 71 | | |

*** F.999 (7, 56) = 4.19

| Baseline vs. Post-Training Eccentricity Assessments | | | | |
|---|---|---|---|---|
| Source of Variance | SS | df | MS | F |
| Trainees | 577 | 8 | | |
| General Transfer Effects | 522 | 1 | 522 | 5.59* |
| Eccentricity | 34 | 1 | 34 | .41 |
| Interaction: Transfer X Eccentricity | 1 | 1 | 1 | .14 |
| Error Transfer Effects | 747 | 8 | 93.38 | |
| Error Eccentricity | 659 | 8 | 82.38 | |
| Error Interaction | 58 | 8 | 7.25 | |
| Total | 2589 | 35 | | |

*F.95 (1,8) = 5.32

(see Table 20). Moreover, post-training peripheral vision two-flash performance increased for eight of the nine trainees. Increases ranged from 2 percent to 83 percent on the block assessments and from 2 percent to 123 percent on the eccentricity measures. Only one trainee failed to demonstrate an improvement in post-training performance and, in this instance, a slight decline occurred. It is interesting to note that this trainee is the same individual that exhibited fatigue-related performance decrements near the end of the training regimen (Trainee $S_2$).

The percentage improvements in velocity discrimination performance were much smaller. General transfer of training to velocity discrimination was extremely modest, on the order of 3 to 5 percent for the trainees as a group. Moreover, the general transfer effects were inconsistent. Six of the ten trainees showed an increase in post-training performance; three trainees exhibited a performance decrement; and one trainee manifested no change.

# DISCUSSION

## Near-Threshold Training Effectiveness

The experimental findings indicate that near-threshold training can improve the accuracy of target detection, recognition, and identification. The trainee group learning curves reflect consistent improvement in target detection, recognition, and identification accuracy at the target temporal durations (visual access times) of 67 and 33 ms. The learning curves of the individual trainees reveal differences in initial capability, learning rate, and ultimate performance level. These differences became more pronounced as the training protocols increased in difficulty (visual access time diminished and task demands escalated). Individual differences were magnified on the relatively difficult target identification protocol, particularly at target temporal durations of 50 ms and below.

The extent of individual performance differences can be illustrated by comparing the learning curves of the superior and poor performers on the target identification protocol at 33-ms visual access time. In this protocol, the trainee discriminated among ten visual-spatial symbols and selected one of five control options, all based on information present for only 33 ms. Despite the complexity of this protocol, one trainee achieved over 90 percent target identification accuracy after 300 training trials and 99 percent accuracy after 500 training trials. Conversely, on the same protocol, another trainee could manage only 41 percent target identification accuracy after 700 training trials.

TABLE 20

General Transfer Improvement in Two-Flash Threshold Performance: Baseline (B) vs. Post-Training (PT)

| Trainee | Performance B | Performance PT | Percentage Change |
|---|---|---|---|
| Block Assessments[a] | | | |
| $G_4$ | 86 | 157 | +83 |
| $S_3$ | 106 | 159 | +50 |
| $P_1$ | 103 | 118 | +15 |
| $P_2$ | 112 | 127 | +13 |
| $G_3$ | 122 | 137 | +12 |
| $G_1$ | 108 | 120 | +11 |
| $P_3$ | 112 | 121 | +8 |
| $S_2$ | 122 | 124 | +2 |
| $S_1$ | 142 | 136 | -4 |
| Group Mean (n = 9) | 112.6 | 133.2 | +18 |
| Eccentricity Assessments[b] | | | |
| $G_4$ | 47 | 105 | +123 |
| $S_3$ | 75 | 109 | +45 |
| $P_2$ | 70 | 81 | +16 |
| $P_3$ | 76 | 88 | +16 |
| $G_1$ | 82 | 94 | +15 |
| $P_1$ | 68 | 77 | +13 |
| $G_3$ | 86 | 91 | +6 |
| $S_2$ | 97 | 99 | +2 |
| $S_1$ | 90 | 84 | -7 |
| Group Mean (n = 9) | 76.8 | 92.0 | +20 |

[a]Trainee performance is the total score based on four two-flash threshold assessment blocks.
[b]Trainee performance is the total score based on two eccentricity assessments.

Individual differences in near-threshold information acquisition and processing performance were expected, even among highly motivated, flight-qualified student pilots. Hartman (1982), for example, postulated that only 20 percent of the combat-ready, fighter-attack pilot population might have the innate perceptual-cognitive aptitude and personal attributes necessary to become superior combat pilots (top one percent). Our limited data suggest that the potential for superior performance in near-threshold information acquisition and processing (thought to be an important dimension of aircrew situational awareness) may reside in only a portion of the general population.

Since few professions depend on heightened sensitivity to low-intensity, fleeting cues, the inherent abilities or aptitudes that contribute to high-level, near-threshold skills are likely to be substantially underdeveloped. Even professions that demand near-threshold information acquisition and processing skills probably develop these skills as a result of long-term, cumulative experience. It is also likely that only a relatively few individuals reach their full performance potential because of the lack of systematic training programs and systems to augment cumulative experience and reduce the time required to reach proficiency.

The baseline versus post-training data show that, in general, performance improved significantly as a result of near-threshold training. Mean increases in group composite performance (combined target detection, recognition, and identification) were 43 percent at 50-ms and 52 percent at 33-ms visual access times. The performance improvement of individual trainees was quite variable; however, nearly all trainees exhibited gains on the composite performance measure. The data at 50 ms shows that all ten trainees manifested performance improvements which ranged from 13 percent to 136 percent. At 33 ms, composite performance increased for nine trainees; improvements ranged from 23 to 128 percent.

Only one trainee failed to increase performance from the baseline to post-training assessment. For this particular trainee, performance declined slightly (3 percent) at 33-ms target duration. However, at 50-ms visual access time, he exhibited a performance improvement of 27 percent.

With regard to the group mean training effects, it is likely that the restriction of range of performance scores at the longer target visual access times attenuated the F ratios used to test statistical significance. Asymptote was reached quite quickly by most trainees at the longer target temporal durations; hence, the magnitude of true differences in trainee aptitude and performance tended to be obscured at longer target SOAs.

The relatively small increase in group mean performance at the 17-ms visual access time appears to reflect the difficulty of direct training transfer to SOAs that are substantially shorter than the training SOA. In the present investigation, for example, near-threshold training occurred at temporal durations of 67 and 33 ms. The data showed that training transferred to an intermediate duration (50 ms), but not to a much briefer visual access time (17 ms).

## General Transfer Effects

It was hypothesized that intensive, near-threshold training would increase the resolving power of perceptual-cognitive processes responsible for acquiring and processing fleeting, short-duration information, and that this enhanced resolving power would transfer to tasks with similar perceptual and cognitive demands. In the case of peripheral vision two-flash threshold, the general transfer of training effects was encouraging. Mean post-training performance was higher on the two-flash assessment blocks (18 percent) as well as on the eccentricity measures (20 percent). The difference between baseline and post-training performance was statistically significant on the two-flash threshold assessment blocks ($p < 0.001$) and eccentricity metrics ($p < 0.05$). Eight of the nine trainees exhibited increased post-training performance; performance improvements ranged from 2 to 83 percent on the assessment blocks and from 2 to 123 percent on the eccentricity measures.

We believe the generic training effects could reflect a strengthening of ambient visual system resolving power. This finding is consistent with earlier work by George Wolford and his colleagues at Dartmouth College (Wolford et al., 1988). Wolford found that performance improvements obtained with the backward masking paradigm were associated with reductions in the two-flash threshold. They assessed the general transfer of near-threshold training effects to two-flash threshold performance using both experimental and control groups. Experimental subjects were assigned to a 19-day pattern masking training regime that involved 2850 training trials at an SOA nearest to an individually-determined baseline performance level of 50 percent accuracy. In the training task, subjects identified strings of three randomly selected consonants (y excluded) that were masked at specified SOAs by randomly selected alphanumeric patterns.

Wolford's training regime was interposed between: (a) pre-training and post-training performance measures that were obtained at six SOAs (including the SOA at which the training occurred), (b) two-flash threshold performance assessments using a single, centrally positioned (foveal) light emitting diode (LED). Pre-training and post-training performance assessments were made on both the experimental and control

groups, but only the experimental group received training during the period between the two assessments.

Wolford et al. found that letter string identification training using backward pattern masking improved two-flash discrimination performance. By the end of training, two-flash discrimination performance increased from 50 to 80 percent at the threshold interflash interval (IFI) that was determined at the baseline session. Two other findings support general transfer effects: (a) subjects who demonstrated the greatest performance improvement during the identification training, also had the largest increase in two-flash discrimination performance; and (b) the training methods produced significant reduction in two-flash threshold (about 9 percent, $p = .0026$).

The findings of Wolford and his associates and those of the present study are highly consistent. The congruity of the findings is even more compelling when several differences in experimental design and approach are considered. Wolford, for example, employed pattern masking in an identification task that used letter symbols as targets. Two-flash discrimination performance was determined from foveal information uptake only. Conversely, in the present investigation, pattern masking was used in target detection, recognition, and identification protocols, all of which used visual-spatial symbols as targets. Additionally, in the present study, two-flash discrimination performance was based on predominantly peripheral information uptake.

Other results reported by Wolford et al. (1988) were also consistent with the findings of the present investigation. For example, the steady improvement of most trainees over time was apparent in both investigations. Further, training at one target duration (SOA) transferred to SOAs on which the individual had not been trained.

The general transfer of training to velocity discrimination performance was positive in direction, but not very strong. This finding may be due to the dissimilarity between the perceptual-cognitive processes involved in target detection, recognition, and identification vis-a-vis velocity discrimination. Despite the possible construct dissimilarity, the transfer effects were in the right direction (post-training velocity discrimination mean performance was 3 to 5 percent higher than the pre-training mean performance). Individual training effects reflect similar positive but weak trends; six of ten trainees exhibited a post-training improvement in velocity discrimination.

## Enhanced Automated Processing

Our theoretical formulations identify automated processing and response automaticity as important components of situational awareness (Hartman & Secrist, 1991; Secrist & Hartman, 1993a). Although they are not central to the present investigation, automated processing and response automaticity appear to be facilitated by the near-threshold training approach; this approach emphasizes consistency in stimulus-response relationships and forces speeded processing of low-intensity, short-duration (fleeting) information. The near-threshold training consistently linked various visual-spatial stimulus symbols to the same responses throughout the training. The stability of these relationships in combination with the rapid-fire presentation of a large number of training trials fostered the development of automated responses. The distinctive characteristics of the specific stimuli (target/nontarget symbols) and the consistency of their meaning within the training situation also aided in the development of automated processing. These conditions enabled the trainee to discriminate and master the determinant or driver cues associated with the various target and nontarget symbols and to relate these cues to the same response programs within each of the three training protocols.

## Effectiveness of Training Methods

The utility of pattern masking in controlling visual access time or target temporal duration in near-threshold training is a function of the relationship between the masking stimulus and the perceptual-cognitive processes involved in acquiring and processing information. These processes operate on information to successively modify and refine the knowledge extracted from sensory inflow (Haber, 1969). Continuous information inflow from multimodal sensory input results in increasingly precise assessments of the external state of affairs. The acquisition and processing of information proceeds without interruption, despite substantial variability in the quality and quantity of the sensory inflow.

The intrusion of the pattern mask temporarily suspends the processing of the original stimulus information by involuntarily demanding the same perceptual and cognitive resources. The interruption in processing caused by the pattern mask diverts the same or closely related perceptual-cognitive resources to the new sensory input. This interpretation fits within a theoretical framework formulated by Neisser (1967) and Turvey (1973). From this perspective, two stages of information processing are crucial to pattern recognition. During the first stage, the perceptual-cognitive processes discriminate, organize, and integrate the figural units of the stimulus array supplied by the sensory information acquisition net. During the second stage,

cognitive processes establish figural unity, object identity, and situational context.

In essence, the outputs of the sensory information acquisition net are context-independent cues or features (first stage) that are structured cognitively (second stage) to establish figural unity within an appropriate situational context (Turvey, 1973). The introduction of a pattern mask can affect either processing stage depending on its timing (SOA). Interruption of either or both stages of pattern recognition terminates the processing of the constituent information at the precise time the pattern mask is administered.

Wide individual differences are thought to exist in the inherent aptitude and developmental potential of the perceptual and cognitive processes responsible for near-threshold information acquisition and processing. Pattern masking techniques address the matter of individual differences quite well. Indeed, pattern masking highlights individual differences because the mask operates on central or cognitive processes that are particularly susceptible to training and experience (Turvey, 1973).

The Wolford et al. (1988) experiments support the hypothesized linkages between pattern masking, central processing, and the trainability of relevant perceptual and cognitive capabilities. They found, for example, that even though performance improved as a result of increased knowledge about the specific targets and pattern masks, the predominant training effect appeared to be attributable to enhanced information acquisition and processing performance. Additional support for the notion of central or cognitive control of near-threshold processes can be found in Lyon's (1987) research. His work indicates that attention is directed to multiple locations within the visual field during the extremely brief millisecond timeframe of a single visual fixation. It is possible that systematic near-threshold training could translate these intrafixation attention shifts into: (a) an increased rate of information acquisition, (b) more rapid extraction of cues from the visual stimulus field, and (c) greater information processing speed and accuracy.

Finally, our findings and those of Wolford et al., when combined with other research (e.g., see reviews by Dixon, 1981; Klatzky, 1984; Marcel, 1983; Secrist, 1986; Secrist & Hartman, 1993c), make it clear that information acquisition and processing performance can be enhanced through the use of pattern masking methodology. Moreover, the findings suggest that the training effects of pattern masking methods can be intensified when they are employed with intensive, rapid-fire repetition of consistent stimulus-response components within an operant paradigm which incorporates appropriate performance feedback. In our view, this approach operates to vigorously

exercise and develop the perceptual-cognitive processes responsible for near-threshold information acquisition and processing. Appropriate central nervous system functions are, in effect, strengthened and conditioned as a result of being driven to respond to increasingly rigorous performance requirements.

## SUMMARY AND CONCLUSIONS

One of the pivotal characteristics that distinguishes superior fighter-attack pilots from their less successful peers is extraordinary situational awareness. Certain primary skills have been identified that are thought to be essential to keen situational awareness. The present investigation focused on the trainability of near-threshold information acquisition and processing skills which are postulated as important components of situational awareness.

This feasibility investigation was designed to serve two purposes: first, to determine the effects of near-threshold training on target detection, recognition, and identification performance; and, second, to assess the general transfer of near-threshold training to improved velocity discrimination performance and to increased resolving power in the peripheral visual system. The near-threshold training employed three general training methods: (a) pattern masking to precisely regulate visual access time; (b) consistent stimulus-response relationships and compressed decision/response time to foster automated processing; and (c) an operant training paradigm which shaped performance with appropriately timed feedback. Ten flight-qualified AFROTC cadets served as trainees for the research. Each trainee received 5040 near-threshold training trials over five consecutive days.

Group learning curves reflected consistent improvement in target detection, recognition, and identification accuracy at target temporal durations down to 33 ms. The individual training effects revealed that near-threshold training assessments were sensitive to differences in trainee capability, learning rate, and performance level. The differences became more pronounced as training protocol difficulty increased and target temporal duration (visual access time) decreased. Individual differences were magnified on the most difficult training protocol (target identification), especially at temporal durations of 50 and 33 ms. In general, the data suggest that 50 ms may be a critical benchmark in detecting differences in inherent ability and predicting ultimate performance level.

Highly significant differences were found between baseline and post-training performance. Mean improvements in group composite performance (target detection, recognition,

and identification) were 43 percent at 50-ms target temporal duration and 52 percent at 33-ms duration. Performance gains by individual trainees were quite variable, ranging from no improvement for one trainee to an increase of 136 percent. The strength of the near-threshold training was emphasized by the consistency of the positive training effects; nearly every trainee manifested at least some improvement.

The general transfer of training data showed that near-threshold training in target detection, recognition, and identification transferred to performance on a peripheral vision two-flash threshold protocol. Group mean performance increased across the two-flash threshold block and eccentricity assessments, averaging 18 and 20 percent, respectively. Eight of nine trainees exhibited increased post-training performance (the tenth trainee lacked complete data on this protocol). The average performance increases for the eight trainees ranged from 2 to 123 percent.

The general transfer of training to velocity discrimination performance was positive in direction, but not very strong (3 to 5 percent increase in group mean performance). It is possible that the performance demands of the near-threshold training protocols vis-a-vis the velocity discrimination protocol were dissimilar and required different perceptual-cognitive capabilities; thus, diminishing the transfer effects.

We have concluded from years of research that near-threshold information acquisition and processing skills are vital to performance in some professions, including the fighter-attack pilot profession. These professions depend on heightened sensitivity to low-intensity, fleeting cues to provide information for decisions that must be made under great time urgency and stress. The near-threshold skills appear to develop slowly as a result of intensive practice and cumulative experience. No systematic training programs or systems presently exist to augment cumulative experience and reduce the time required to reach proficiency. The research reported here indicates that near-threshold skills are trainable and suggests that such training strengthens the perceptual and cognitive processes involved in near-threshold information acquisition and processing.

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